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Spatial variations in catch characteristics in the California spiny lobster commercial fishery with implications for management

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Spatial variations in catch characteristics in the California spiny lobster commercial fishery with implications for management

A Thesis submitted in partial satisfaction of the requirements for the degree

Master of Arts in Ecology, Evolution and Marine Biology

by

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DEDICATION

This thesis is dedicated to my parents, Jeff and Karen Yaeger, and brother, John Yaeger, for their love, patience and encouragement.

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ABSTRACT

Spatial variations in catch characteristics in the California spiny lobster commercial fishery with implications for management

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Consistent with the California Marine Life Management Act, a fishery management plan (FMP) is being developed for the state's spiny lobster fishery to help sustain it over the long term. The FMP requires identification of suitable protocols for collecting data, as well as the best available scientific information to inform management. The main source of information currently available to fishery managers is the commercial logbook and landing receipts. These sources of data allow managers to determine three reference points used to gauge the health of the fishery: catch, catch per unit effort (CPUE) and spawning potential ratio (SPR). The fishery is currently managed as a single area, but given the different habitats and environmental conditions occurring in the Southern California Bight, fishery parameters may vary biogeographically. To explore spatial trends within the California spiny lobster commercial fishery and how these may affect management, I analyzed three years of essential fisheries information collected through a collaborative at-sea sampling program (CASP), where commercial fishermen collect data on their catch while conducting their day-to-day fishing activities.

My analyses of CASP data identified significant spatial patterns in lobster size distributions, biomass per trap, sex ratios, reproductive output, and the number sub-legal lobsters for three regions; South, North Coast and North(west) Islands. The majority of lobsters harvested in the South were small, averaging 86 mm among years, representing recent recruits to the fishery as they are just over legal size (82.5 mm). Given the small legal size and high fishing effort in this region commercial fishing may be near its maximum exploitation rate there. Unlike the South, legal lobster in North Coast and North(west) Islands are much larger averaging 90 mm and 97 mm among years respectively. The larger legal size and the lower fishing effort in these regions suggest commercial fishing may be below the maximum exploitation rate there. While the South may have a high exploitation rate, this region had significantly more sub-legal lobster (i.e., potential future recruits) compared to both the North Coast and North(west) Islands, which may help to mitigate the high exploration rate. Further, in the second year, sex ratios of legal lobster indicated a slight trend toward higher removal of female lobster in the North Coast (56:44) and North(west) Islands (64:36) regions as compared to the South (47:53), suggesting higher trap vulnerability and potentially decreased reproductive capacity in those two regions. Sub-legal sex ratios were female biased (>60%) in all regions for most years, suggesting additional impacts to trap vulnerability and reproductive capacity. Lastly, assessments of reproductive capacity suggest that egg production per trap is greatest in the South (408,000 eggs per trap) compared to both the North Coast (166,000 eggs per trap) and North(west) Islands (112,000 eggs per trap). This finding is influenced by the large number of mature sub-legal lobsters that will remain in the population in the South.

The essential fisheries information (EFI) collected by the CASP augments existing CDFW management data and can be used to inform two of the three reference pointed being considered for the FMP; CPUE and spawning potential ratio (SPR). My comparisons of CASP and CDFW data identified several shortcomings with commercial logbook and landings data. First, fishermen may estimate the number of trap pulls for the commercial logbook, which affects the accuracy of the CPUE reference point, while CASP data is recorded per trap providing an accurate count of the number of traps. Logbook data also contain many erroneous and missing entries that are time consuming to filter out. Second, issues with correlating logbook to landing receipt data affects the calculation of average weight, which is used in fishery models to determine the SPR reference point. I determined that the average weight from logbook/landings data was similar to that calculated from CASP data for the South and North Coast. However, average weight determined from the logbook/landings for the North(west) Islands was larger than CASP data; correlating to 114 mm and 97 mm carapace length respectively. Other studies support the findings of the CASP data. Given these issues, CASP data may be more efficient, accurate and cost-effective for informing management on the status of the fishery.

Overall, the regional variation in catch characteristics suggests area-based management may be more appropriate for the California lobster fishery. Further, the current model used to determine SPR reference point should consider the abundance of sub-legal lobsters and higher trap vulnerability for female lobsters, as it impacts the reproductive capacity of each region thereby warranting the continued collection of size and sex data. The demonstrated utility of the pilot CASP program for collecting fishery-dependent EFI across the entire range of the fishery, along with the critical need for such data as identified by a recent scientific review of the FMP, has generated support for implementing an ongoing CASP program to inform long-term management of the lobster fishery.

INTRODUCTION

The California spiny lobster, *Panulirus interruptus*, is an ecologically important species that has supported valuable commercial and recreational fisheries since the late 1800’s (Wilson 1948; Odemar et al. 1975; Barsky 2001; Neilson 2011; CDFW 2014). *Panulirus interruptus* occurs on rocky reefs predominantly from Point Conception, California, USA to Magdelena Bay, Baja California, Mexico, but has been found as far north as Monterey and as far south as Manzanillo, Mexico (Wilson 1948; Schmitt 1921; Johnson and Snook 1927). In California, the primary geographic range and fishing grounds of *P. interruptus* occur in the Southern California Bight (SCB). This region is characterized by considerable variation in abiotic factors, including water temperature and upwelling. The SCB, extends from Point Conception to San Diego, and includes the Santa Barbara Channel at the northern end of the SCB, a transition zone where warm equatorial waters mix with cold northern waters. The remainder of the SCB is influenced by warm waters from Baja, California, Mexico. Throughout the SCB, complex circulation patterns create eddies that further influence the mixing and flow of warm and cold water in the region, resulting in widely varying temperatures within the SCB. For example, San Nicolas Island, the most westerly island in the region, experiences an average peak sea surface temperature of around 18°C (NOAA 2012) as do the Northern Channel Islands. In comparison, areas off San Diego have an average peak sea surface temperature of about 22°C, and along the coast off Los Angeles 20°C (NOAA 2012). Upwelling also varies throughout the bight, being most predominant in the Santa Barbara Channel at the northern end of the SCB. As a result, productivity is typically higher there.

In California, commercial fishing for lobster occurs throughout the SCB, with about 155 active fishermen as of 2011 (Neilson 2011). The fishery is restricted to early October to mid-March to protect egg brooding females, which are present in the spring and summer. A minimum lobster size of 82.6 mm also allows lobsters to reproduce before being harvested, and entry into the fishery is limited to control the amount of fishing effort (CDFW 2014). Fishing is also prohibited in several areas, including 17 coastal and 20 island marine protected areas (CDFW 2014). The majority of landings (80%) typically occur within the first half of the fishing season, until around mid-January (Neilson 2011). Commercial landings have fluctuated through time, but since 2000 the landings have been relatively stable at around 300,000-400,000 kg each season (CDFW 2014). While little is known about the recreational harvest, recent estimates by the California Department of Fish and Wildlife (CDFW) suggest an average of an additional 160,000 kg per year, constituting 28-38% of the total catch (commercial and recreational combined). Currently both the recreational and commercial fisheries are managed together for the entire range within California.

In accordance with the state Marine Life Management Act (MLMA) of 1999, a fishery management plan (FMP) is being developed to ensure the future sustainability of the California spiny lobster fishery. The FMP designates a harvest control rule to prevent, detect and recover from overfishing (CDFW 2014). The harvest control rule consists of three 'reference points' to gauge the health of the fishery: catch, catch per unit effort (CPUE), and spawning potential ratio (SPR). SPR is the ratio of the number of eggs produced by a fished population divided by the number of eggs produced by a virgin (unfished) population. Of the three reference points, a drop in SPR alone requires management action, while a drop in either the catch or CPUE only dictates an optional response.

As stipulated in the MLMA, the FMP must use the best information available to inform the reference points to ensure the fishery is properly managed. Currently, the managers rely primarily on the commercial logbook and landing receipts to calculate the three reference points. The commercial logbooks provide information on the number of traps pulled, legal lobsters retained and sub-legal lobsters released within a 16.1 km by 16.1 km block during each season. The CPUE reference point is determined directly from this information. The landing receipts provide information on the total weight of the landed catch, which managers use to determine the catch reference point. Landing receipts correspond to individual logbook data, allowing managers to calculate the average weight of the lobsters retained. The average weight of the lobsters retained is used to determine the SPR reference point via the lobster fishery model known as the Parrish Cable Model (CDFW 2014).

While the landings and logbooks provide some useful data, there are shortcomings that may affect the accuracy of the reference points. For example, fishermen have stated that the number of traps pulled and the number of sub-legal lobsters released, as recorded in logbooks, is often an estimate. This reduces the accuracy of the CPUE reference point. In addition, there is often a discrepancy in matching logbook information to landing receipts, which reduces the accuracy of the average weight of the catch used in the Parrish Cable Model and subsequent calculation of SPR (Neilson 2011).

Further, the Parrish Cable model is considered an adequate model given the current data that are available, but basic essential fisheries information is lacking throughout the range of the lobster fishery. As a result, the model has used data, such as growth and size at maturity that are derived primarily from spatially and temporally isolated studies, rather than bight-wide data collected over many years. In particular, the majority of data have been obtained from studies conducted at either the Northern Channel Islands, Catalina Island, or Palos Verdes on the mainland, which vary biogeographically. Further, information on size structure, number of recruits and sex ratios of the catch are not factored into some of the calculations regarding SPR. A recent scientific review of the model identified such gaps, recommending that additional data should be collected and used in the current models. This will also facilitate more robust fishery models for managing the California lobster fishery (Field et al. 2015).

The development of a pilot Collaborative At-Sea Sampling Program (CASP) for the California spiny lobster commercial fishery – where commercial fishermen collect data on their catch at sea while conducting their day-to-day fishing activities, sharing and discussing it with scientists and managers -- has resulted in the collection of essential fisheries information from regions throughout the SCB. These data have enabled me to explore spatial trends within the commercial fishery and how these may affect management. While I recognize the importance of integrating similar information about the recreational fishery – as it too is likely impacting the population – it was not within the scope of my study. Specifically, I investigated variation in catch characteristics of the California lobster fishery including legal and sub-legal CPUE, size structure, biomass, number of lobsters entering the fishery, sex ratios, and reproductive output. Given the different habitats and environmental conditions occurring in the SCB, I hypothesized that these parameters may vary biogeographically. Further, I examined whether the sex ratio of the catch deviated from an even (50:50) ratio, the ratio used in the fishery model. Lastly, I compared estimates of the three reference points used in the lobster FMP calculated from the CDFW data and the

CASP data. Based on my investigations I provide a discussion about how, if at all, my findings might enhance current management of the fishery.

METHODS

Study Area

Data were collected throughout the spiny lobster (*Panulirus interruptus*) fishing grounds in the Southern California Bight, from south of Point Conception, Santa Barbara County to the Mexican border, including both island and coastal mainland areas (Fig. 1). Coastal sites sampled from south to north included Point Loma, La Jolla, Dana Point, Newport Beach, Huntington Beach, Long Beach, Malibu, Oxnard, Ventura and Santa Barbara. Six offshore islands were sampled from south to north included San Clemente Island, Catalina Island, San Nicolas Island, Santa Barbara Island, Santa Cruz Island and Santa Rosa Island, along with Cortes Banks, an offshore reef.

Sampling Methods

Data were collected in collaboration with commercial lobster trap fishermen through a collaborative at-sea sampling program (CASP) during the 2012-13, 2013-14, and 2014-15 spiny lobster fishing seasons, which runs from early October to mid-March. Lobster traps used in this study followed commercial gear restrictions, including a single 6.0 cm by 29.2 cm escape port that allows small, sub-legal lobsters to leave the trap. Traps were made of galvanized steel or vinyl coated wire with a mesh size of 5.0 cm by 10.1 cm. The majority of traps measured 0.91m by 0.71 m, with 1.02 m by 0.71 m commonly used at many of the island sites (Table 1). Salmon and mackerel were the most commonly used bait types, but other bait was sometimes used (Table 2). The amount of time from when the traps were baited and then serviced (i.e. the “soak time”) was typically 2-4 days, but in a few cases it was as short as one day or longer than four days (Table 3). Traps are required to be serviced every four days, weather conditions permitting.

Fishermen collected information on the number of legal and sub-legal lobsters per trap, carapace length, and sex. Counts of legal and sub-legal lobsters were taken on every trap in year one, and for a subset of traps (typically about 60 traps per trip) in years two and three. Traps with no lobsters were counted and recorded as empty. Size (carapace length, CL), was measured from the rostrum to the tip of the carapace to the nearest 0.01 mm using a digital caliper (Mitutoyo model CD-8’’PSX) for every lobster from a subsample of traps (at least 12 traps). The sex of every measured lobster was also determined by visually examining the size of the pleopods; females having larger pleopods that cover the underside of each abdominal section of the tail (DAR 2015). The resulting data set for the three years included counts of 28,328 lobsters and size and sex information for 9,458 lobsters (Table 4).

Data Analysis

I compared the CASP catch data among three regions that differed in geographic position and oceanographic conditions; South, North Coast and North(west) Islands (Fig. 1). The South region encompassed the area between San Diego and Dana Point including San Clemente and Catalina Islands. North Coast region includes the mainland coastal region between Newport and Santa Barbara County. North(west) Islands includes the Northern

Channel Islands, Santa Barbara Island, San Nicholas Island and Cortez Bank. While the latter two sites occur off the coast of some Southern locations, circulation patterns and temperature data suggest both have environmental conditions influence by cooler northerly waters (NOAA 2012). For example, Cortez Banks experiences an average peak sea surface temperature around 19°C, while San Clemente Island, included in the South, is around 21°C (NOAA 2012).

I used the metrics of catch-per-unit-effort (CPUE), size structure, number of recruits and sex ratio to compare catch characteristics among the three regions. Each metric was computed for every year. Traps that were lost or poached were not included in these analyses. The CPUE was calculated by dividing the number of lobsters (legal or sub-legal) by the number of traps sampled. I compared the size structure of the fished population among regions by grouping the CL measurements into 6 mm size classes, which is the estimated yearly growth rate of spiny lobster used in the CDFW stock assessment models (Neilson, 2011). I determined the proportion of sub-legal lobsters entering the fishery the following year (year-1) for each region by dividing the number of lobster occurring in the size class just below legal size (76.5 mm - 82.5 mm) by the total number of sub-legal lobsters measured. The number of next year fishery recruits per trap was determined by multiplying the number of sub-legal lobsters in each sample trap by the proportion of sub-legal lobsters that will enter the fishery the following year. The sex ratio of legal and sub-legal lobsters was calculated by dividing the number of legal or sub-legal females by the total number of lobster in each of the respective categories.

I also calculated the average weight of legal lobster for each region per year by converting CL to mass using the function: $\log(W) = \log(1.03992E\text{-}5) + 2.4829 \log(L)$, where W is the mass in kilograms and L is the carapace length in millimeters (Neilson 2011). To determine biomass per trap, I: 1) determined the size frequency distribution binned in 0.1 mm classes, for each region with legal and sub-legal lobsters separated, 2) multiplied the legal and sub-legal size frequency distribution by the number of legal and sub-legal lobsters in the sample traps, resulting in the number of lobster in each size class, 3) multiplied number of lobster in each size class by the mass of a lobster in the corresponding size class, resulting in the total mass per size class, 4) summed the mass for legal and sub-legal lobsters and 5) divided the total mass of legal and sub-legal categories by the number of sample traps to account for trapping effort, resulting in a measure of biomass per trap.

I compared the reproductive capacity of the catch among regions by calculating fecundity for each region. I used Lindberg's table on size and number of eggs to create an equation describing the relationship between carapace length and number of eggs (Lindberg 1955). This resulted in a linear relationship of $y = 3746x - 764951$ ($R^2 = 0.98$) for individuals ≤ 71.6 mm in total length (the smallest size in Lindberg's (1955) fecundity table) where y is the number of eggs and x is the total length in millimeters. Since Lindberg used total length (TL) as the measurement of size, I converted CASP CL to TL using the Nielson (2011) conversion; CL= 0.333(TL). To calculate fecundity I: 1) determined the size frequency distribution binned in 0.1 mm classes, for each region with legal and sub-legal lobsters separated, 2) multiplied the legal and sub-legal size frequency distribution by the number of legal and sub-legal lobsters in the sample traps, resulting in the number of lobster in each size class, 3) multiplied number of lobster in each size class by the number of eggs produced by a lobster in the corresponding size class, resulting in the number of eggs produced per size class, 4) summed the eggs produced for legal and sub-legal lobsters and 5) divided the fecundity of legal and sub-legal categories of each region by the number of sample traps in each to account for trapping effort, resulting in a measure of fecundity per trap (number of eggs produced per trap).

Commercial logbook and landings data from October through January for the 2012-13 and 2013-14 fishing seasons (correlating to CASP year 1 and 2) were used to compare CPUE and average mass of the legal catch to CASP. Logbook and landings data were edited prior to analysis to remove entries with duplicate ID numbers, as suggested by CDFW (Buck, pers. comm.). I calculated averages by using the two fishing seasons as replicates. CPUE was calculated by dividing the number of lobsters retained by the number of traps pulled per the logbook ID. The average mass of lobster retained was calculated by dividing the total number of lobsters retained by the total weight on the landing receipts. Only logbook entries with matching landing receipts were included in this analysis.

Statistical Comparisons

Three types of analyses were conducted using SAS 9.4. First, a one-way analysis of variance (ANOVA) with Tukey-Kramer post-hoc tests was used to compare CASP data on mean CL, mean mass, CPUE, fecundity, and the number of next year recruits among regions for each year. In addition, a mixed model with year as a random factor and region as a fixed factor was used to account for differences in years. Second, a chi-square test of independence was used to determine differences in size frequency distributions, proportion of next year recruits and sex ratios among regions. A chi-square test was also used to test deviations from a 50:50 sex ratio – the ratio used in models for the lobster population -- for each region. Third, paired Student t-tests were used to test differences between estimates of CPUE and the average mass of legal lobsters derived from CASP to those derived from the CDFW data (commercial logbook and landing receipts). Numeric data were square root-transformed and proportions were arcsine-transformed to normalize them prior to analysis.

RESULTS

Catch-Per-Unit Effort (CPUE)

Overall, there was a highly significant interaction between region and year ($F = 7.57$, $p<0.001$; Table 5) on legal CPUE (i.e. catch per trap), but no difference among regions ($p=0.71$) or years ($p=0.59$). Given the significant interaction I explored differences among region for each year (Table 6, Fig. 2). There was no significant difference in legal CPUE among regions in year one or year three with legal CPUE values ranging from 0.4 to 0.6. However, in year two legal CPUE in the North Coast ($\bar{x}= 0.66 \pm 0.03$) was significantly higher than both the South ($\bar{x}= 0.42 \pm 0.02$; $p<0.05$) and North(west) Islands ($\bar{x}= 0.54 \pm 0.02$; $p<0.05$). The North(west) Islands was not significantly different than the South ($p>0.05$) in year 2. The legal CPUE for all three regions combined, averaged across years, was 0.53 (± 0.02 S.E.). Legal CPUE, averaged across years, was 0.49 (± 0.04) in the South, 0.58 (± 0.06) in the North Coast and 0.54 (± 0.04) in the North(west) Islands.

There was also a highly significant interaction between region and year for sub-legal CPUE ($F = 25.61$, $p=0.0001$; Table 5), with region significant ($p<0.004$) but not year ($p=0.44$). As a result, I explored differences among regions for each year (Table 6, Fig. 2). The South region consistently had the most sub-legal lobsters per trap ranging from 2.73 to

4.15, followed by the North Coast ranging from 0.88 to 1.15, and North(west) Islands ranging from 0.15 to 0.25. The sub-legal CPUE for all three regions combined, averaged across years, was 1.94 (± 0.09 S.E.). Sub-legal CPUE, averaged across years, was 3.63 (± 0.45) in the South, 1.01 (± 0.08) in the North Coast and 0.20 (± 0.03) in the North(west) Islands.

Size Distribution

The size distribution of sampled lobsters differed significantly among regions for all years (p=0.0001;Table 7, Fig. 3). The South region was dominated by sub-legal lobsters that would be entering the fishery next year as recruits (Year -1) (i.e., 76.6 – 82.5 mm) and legal lobsters that had just recruited into the fishery (i.e., 82.6 – 88.5 mm); large legal lobsters (>94.5 mm CL) were rarely caught in this region. The North(west) Islands region was dominated by large legal lobsters; few sub-legal lobsters were caught there. The size distribution in the North Coast region was intermediate between the South and North(west) Islands regions. Compared to the South region, the North Coast region had more large legal lobsters but fewer sub-legal lobsters. Conversely, compared to the North(west) Islands region, the North Coast region had fewer large legal lobsters but more sub-legal lobsters. This pattern was consistent for all years with the exception of the legal lobster size distribution in year one for the North Coast and South regions not being significantly different (x^2 = 0.09; df=3, p=0.99).

Mean Lobster Size

There was a highly significant interaction between year and region on the mean size of legal lobsters ($F = 9.35$, $p<0.001$; Table 8), with region significant ($p=0.0036$) but not year ($p=0.55$). Because of the interaction, we explored differences among regions within each year (Table 9, Fig. 4). In Year one, there was no significant difference in legal lobster size between the South ($\bar{x} = 86.0 \pm 0.5$ S.E.) and North Coast regions ($\bar{x} = 86.3 \pm 0.7$) ($p>0.05$), although legal lobster size of the North(west) Islands ($\bar{x} = 98.5 \pm 1.5$) was significantly larger than both the South and North Coast. In year two and three all regions were significantly different ($p<0.0001$). The South region had the smallest legal sized lobsters in year two ($\bar{x} = 84.8 \pm 0.2$) and three ($\bar{x} = 86.0 \pm 0.3$), followed by the North Coast (Yr. 2: $\bar{x} = 91.6 \pm 0.4$; Yr. 3: $\bar{x} = 90.9 \pm 0.4$) and North(west) Islands region (Yr. 2: $\bar{x} = 94.6 \pm 0.7$; Yr. 3: $\bar{x} = 98.4 \pm 0.9$), respectively. Mean size of legal lobster, averaged across years, was 85.6 ($\pm$ 0.4) in the South, 89.6 ($\pm$ 1.7) in the North Coast, and 97.2 ($\pm$ 1.3) in the North(west) Islands.

There was a significant interaction between year and region on the mean size of sub-legal lobsters ($F = 5.51$, $p< 0.001$; Table 8), but region ($p=0.82$) and year ($p=0.10$) were not significant. As a result, the effect of region was evaluated within each year (Table 9, Fig. 4). In years one and two, the size of sub-legal lobster was only significantly different between the South and North Coast regions. In year one, the South region had larger sub-legal lobsters compared to the North Coast region ($\bar{x} = 78.6 \pm 0.2$ and $\bar{x} = 77.4 \pm 0.5$ respectively). The opposite pattern was seen in year two; North Coast region had larger sub-legal lobsters ($\bar{x} = 78.8 \pm 0.1$), compared the South region ($\bar{x} = 78.2 \pm 0.1$). In year three, the North(west) Islands had significantly larger sub-legal lobsters ($\bar{x} = 80.3 \pm 0.2$) than both the South ($\bar{x} = 78.6 \pm 0.1$, $p<0.05$) and the North Coast ($\bar{x} = 78.9 \pm 0.2$, $p<0.05$). The South and North Coast were not significantly different in year three ($p>0.05$). Mean size of sub-legal lobster, averaged across years, was 78.5 (± 0.2) in the South, 78.4 (±0.5) in the North Coast and 78.8 (± 0.8) in the North(west) Islands.

Legal Lobster Weight

There was a significant interaction between year and region on the mean weight of legal lobsters ($F= 9.10$, $p=0.0001$; Table 10) with region significant ($p=0.0041$) but not year ($p=0.59$). Since there was an interaction between region and year on legal lobster weight, we explored differences among regions within each year (Table 11, Fig. 5). The North(west) Islands region had the largest average weight followed by the North Coast and South Coast, respectively for years 2 and 3. In year one, legal lobster weight in the North Coast region ($\bar{x}= 0.67 \pm 0.02$) did not differ significantly from the South region ($\bar{x}= 0.67 \pm 0.01$) ($p>0.05$). However, legal lobster weight in the North(west) Islands ($\bar{x}= 0.97 \pm 0.05$) was significantly different from both the South and North Coast in year one ($p<0.05$). The mean legal lobster weight for all three regions combined, averaged across years, was 0.79 (± 0.001 S.E.). Mean legal lobster weight, averaged across years, was 0.66 (± 0.01) in the South, 0.75 (± 0.04) in the North Coast and 0.94 (± 0.03) in the North(west) Islands.

Biomass Per Trap

There was a significant interaction between years and regions ($F=9.25$ $p=0.0001$; Table 12) on legal biomass per trap, but region ($p= 0.15$) and year ($p=0.58$) were not significant. Since there was an interaction between region and year on legal biomass per trap, I explored differences among regions within each year (Table 13, Fig. 6). In year one, there was no significant difference in legal biomass per trap among regions ($p=0.05$). Legal biomass per trap was significantly different among some regions in year two ($p=0.0001$) and three ($p=0.0001$). In year two, legal biomass per trap was significantly smaller in the South region ($\bar{x}= 0.28 \pm 0.01$) than the North Coast ($\bar{x}= 0.52 \pm 0.02$, $p<0.05$) and the North(west) Islands region ($\bar{x}= 0.50 \pm 0.03$, $p<0.05$). The North Coast and North(west) Islands were not significantly different in year two ($p>0.05$). In year three, legal biomass per trap was significantly larger in the North(west) Islands ($\bar{x}= 0.56 \pm 0.04$) than both the South ($\bar{x}= 0.33 \pm 0.01$, $p<0.05$) and North Coast regions ($\bar{x}= 0.47 \pm 0.02$, $p<0.05$). The North Coast and South regions were not significantly different in year three ($p>0.05$). Legal biomass per trap, averaged across years, was 0.32 (± 0.02) in the South, 0.45 (± 0.04) in the North Coast and 0.49 (± 0.04) in the North(west) Islands.

There was a significant year and region interaction ($F= 25.53$; $p=0.0001$; Table 12) on sub-legal biomass per trap, with region significant ($p=0.0004$) but not year ($p=0.44$). As a result, the effect of region was evaluated within each year (Table 13, Fig. 6). Sub-legal mass per trap was consistently highest in the South region ranging from 1.44 to 2.19, followed by the North Coast ranging from 0.47 to 0.62 and North(west) Islands ranging from 0.08 to 0.13. Sub-legal biomass per trap, averaged across years, was 1.92 (± 0.24) in the South, 0.54 (± 0.04) in the North Coast and 0.11 (± 0.01) in the North(west) Islands.

There was a significant year and region interaction ($F= 12.13$, $p=0.0001$; Table 12) in total biomass per trap, with region significantly ($p=0.0004$) but not year ($p=0.44$). As a result, the effect of region was evaluated within each year (Table 13, Fig. 6). Total biomass per trap was consistently highest in the South Region ranging from 1.77 to 2.55 followed by the North Coast ranging from 0.98 to 1.00 and North(west) Islands ranging from 0.54 to

0.64. Total biomass per trap, averaged across years, was 2.24 (± 0.24) in the South, 0.99 (± 0.004) in the North Coast and 0.60 (± 0.03) in the North(west) Islands.

Next Year Fishery Recruits

The proportion of the sub-legal catch that will enter the fishery the following year was not significantly different among regions (x^2 = 0.2333, p=0.89; Fig. 7) at about 80% for the sub-legal catch (North(west) Islands, 82.2%; North Coast, 80.6%; South, 79.4%). While there was variation within regions between years in the proportion of sub-legals that will enter the fishery the following year, regions were not significantly different in any year.

By contrast, there was a significant interaction between region and year in the number of next year fishery recruits per trap (F=22.46, p=0.0001; Table 14), with region significant (p=0.0003), but not year (p=0.53). As a result, the effect of region was evaluated within each year (Table 15, Fig. 8). There was a consistent trend of more next year recruits per trap in the South ranging from 2.22 to 3.40, followed by the North Coast ranging from 0.70 to 0.83 and North(west) Islands ranging from 0.14 to 0.19. The number of next year fishery recruits per trap, averaged across years, was 2.90 (± 0.35) in the South, 0.77 (± 0.04) in the North Coast and 0.16 (± 0.02) in the North(west) Islands.

Sex Ratios

Legal lobster sex ratio differed among regions for some but not all years (Table 16, Fig. 9). In year two the legal sex ratio differed significantly among regions (x^2 = 17.52, p= 0.0002). However, in year one and three there was no significant difference in legal sex ratios among regions (x^2 = 0.52, p= 0.77, x^2 = 0.34, p= 0.84, respectfully).

The legal lobster sex ratio differed from the expected 50:50 (F:M) sex ratio assumed for the population (Lindberg 1955) in some regions in year two, but no regions differed in years one and three (Table 17, Fig. 9). In year two, the sex ratio was significantly higher than the expected 50:50 (F:M) sex ratio for the North Coast (56.0:44.0, $x^2 = 12.27$, $p=0.0005$) and North(west) Islands (64.1:35.9, $x^2 = 31.68$, $p= 0.0001$). The South was not significantly different from 50:50 (47.1:52.9, $x^2 = 0.76$, $p= 0.38$).

Sub-legal lobster sex ratios differed significantly among regions for all three years (Table 16; Fig. 9). The sub-legal sex ratio was significantly female biased in the South and North Coast region for all years and the North(west) Islands for year two and three (Table 17). In year one, the North(west) Islands had a higher sub-legal male prevalence but was not significantly different than 50:50 (40.0:60.0, $x^2 = 1.20$, $p=0.2733$).

<u>Fecundity</u>

There was significant region and year interaction ($F=10.82$, $p=0.0001$; Table 18) on legal lobster egg production per trap, but no significance in region ($p=0.07$) or year ($p= 0.18$). Since there was a significant interaction between region and year, I explored differences among regions (Table 19, Fig. 10). In year one, legal egg production per trap was significantly lower in the South ($\bar{x}$= 59,000 ± 3,100 S.E.) than the North(west) Islands ($\bar{x}$= 78,000 ± 3,400, $p<0.05$). The North Coast was not significantly different than the North(west) Islands ($p>0.05$) or South ($p>0.05$), in year one. In year two, legal egg production per trap was significantly lower in the South ($\bar{x}$= 39,000 ± 1,600) than both the North Coast ($\bar{x}$= 96,000 ± 3,900, $p<0.05$) and North(west) Islands ($\bar{x}$= 110,000 ± 7,000 , $p<0.05$). However, legal egg production per trap in the North Coast and North(west) Islands was not significantly different (p>0.05) in year two. In year three, legal egg production per trap was significantly different in all regions (p= 0.0001), with legal lobsters contributing significantly more eggs per trap in the North(west) Islands ($\bar{x}$= 103,000 ± 7,500), followed the North Coast ($\bar{x}$= 82,000 ± 4,300) and South ($\bar{x}$= 82,000 ± 1,900), respectively. Legal egg production per trap, averaged across years, was 49,000 (± 5,600) in the South, 83,000 (± 7,200) in the North Coast and 98,000 (± 10,000) in the North(west) Islands.

There was a significant region and year interaction (F=20.38, p= 0.0001; Table 18) on sub-legal lobster egg production per trap, with region significant (p=0.0002), but not year (p=0.36). As a result, the effect of region was evaluated within each year (Table 19, Fig. 10). Sub-legal egg production per trap was consistently highest in the South ranging from 273,000 to 414,000, followed by the North Coast ranging from 74,000 to 95,100 eggs per trap and North(west) Islands ranging from 10,600 to 18,300. Sub-legal egg production per trap, averaged across years, was 360,000 (± 43,000) in the South, 83,000 (± 6,200) in the North Coast,and 14,000 (± 2,200) in the North(west) Islands.

There was significant region and year interaction (F= 9.39, p=0.0001; Table 18) on total (legal and sub-legal) egg production per trap, with region significant (p=0.0002), but not year (p=0.18). As a result, the effect of region was evaluated within each year (Table 19, Fig. 10). The total egg production per trap was consistently highest in the South ranging from 324,000 to 473,000 followed by the North Coast ranging from 157,000 to 176,000 and North(west) Islands region ranging from 88,500 to 130,000. The total egg production per trap, averaged across years, was 408,000 (± 44,000) in the South, 170,000 (± 5,500) in the North Coast and 110,000 (± 12,000) in the North(west) Islands.

Comparison of CDFW and CASP data

Mean legal CPUE for all regions combined derived from CDFW data was 0.53 (S.E.=0.02) and was not significantly different from the corresponding years of CASP data on legal CPUE ($\bar{x}$= 0.52, S.E.= 0.02, t=0.38, p= 0.77). Separated out to regions, mean legal CPUE from CDFW data for the North Coast ($\bar{x}$= 0.53 ± 0.01 S.E.), South ($\bar{x}$= 0.56 ± 0.007) and North(west) Islands ($\bar{x}$= 0.47 ± 0.03) was not significantly different from the corresponding CASP data on legal CPUE for the North Coast ($\bar{x}$= 0.57 ± 0.1, t=033, p= 0.80), South ($\bar{x}$= 0.48 ± 0.06, t= 1.61 p= 0.35) or North(west) Islands ($\bar{x}$= 0.50 ± 0.02, t= 0.35, p= 0.78).

The mean weight of legal lobsters for all regions derived from the two years of CDFW data was 0.78 kg (S.E.=0.001) and was not significantly different from the corresponding CASP data mean weight of 0.79 kg (S.E.= 0.001) (t= 5.21, p= 0.12). Separated out to regions, mean weight from CDFW data for the North Coast ($\bar{x}$= 0.78 ± 0.02) and South ($\bar{x}$= 0.66 ± 0.007) was not significantly different from the CASP data on mean weight in the North Coast ($\bar{x}$= 0.73 ± 0.06, t=0.51, p= 0.70) and South ($\bar{x}$= 0.65 ± 0.01, t= 0.54 p= 0.68). While the difference was large, CDFW average weight for the North(west) Islands ($\bar{x}$= 1.33 ± 0.01) was not significantly different from the North(west) Islands in the CASP data ($\bar{x}$= 0.92 ± 0.05, t=11.01, p= 0.058).

DISCUSSION

Regional catch characteristics

Characteristics of the lobster fishery catch varied among the South, North Coast and North(west) Islands regions. Notably, although the average catch (as CPUE) was similar among regions, large lobsters (>89mm CL) composed a much greater percentage of the catch in the two northern regions. This pattern was accompanied by a much higher catch of sub-legal lobsters in the South compared to the two northern regions. My CASP results are consistent with the commercial logbook data for both of these findings (Neilson 2011; CDFW Commercial Fishery Landings Receipt and Logbook Data 2012-2014).

The lower catch of larger legal lobsters in the South could be the result of much greater fishing pressure in that region, resulting in nearly all legal lobster being harvested each season. This possibility is supported by CDFW commercial logbook data (October to January 2012-2014) indicating that trapping effort in the South was much higher, comprising more than half (53%) of the total trap pulls across regions, followed by the North Coast (25%) and North(west) Islands (22%). Further, the commercial logbook data show a sharp decline in legal lobster CPUE as the season progresses in the South, suggesting depletion, while this decline is not as significant in the North(west) Islands and North Coast regions. My calculation of the mean legal CPUE of 0.56 in the South from the CDFW data is for the combined months of October to January, however the legal CPUE is much higher in the first two weeks of the fishing season, averaging 0.84 legal lobsters per trap in the South. The much higher catch of sub-legal lobsters in the South compared with the Northern regions suggests that the lower catch of larger legal lobsters in the South would not be due to recruitment limitation into the fishery.

At least two possibilities may explain the varying levels of sub-legals seen among regions. First, there may be varying levels of puerulus recruitment. There is much debate over recruitment dynamics of *P. interruptus* (Lindberg 1955; Johnson 1960; Pringle 1986; Koslow et al. 2012), however the majority of studies have shown periods of warm water, such as El Niño years, increase lobster phyllosoma abundance throughout the range of the California fishery (Johnson 1960; Pringle 1986; Koslow et al. 2012). It may be that the comparatively warmer waters, typical of the South region, are more conducive to lobster settlement. In comparison the North(west) Islands and North Coast regions are at the northern limit of the core range of *P. interruptus*. As recruitment dynamics of *P. interruptus* are largely unknown, future research is needed to determine larval sources and sinks.

On the other hand, the lower CPUE of sub-legal relative to legal lobsters in the North(west) Islands may be due to fishermen trapping in areas where sub-legal lobsters are not abundant, as some fishermen have indicated (California spiny lobster fisherman, pers. comm.). A previous study at Santa Cruz Island, in the North(west) Islands region, documented highly variable lobster size distributions among reefs and that large lobsters prefer high relief and structurally complex reef sites (Kay 2011). Further, Lindberg (1955) reported that large male lobsters forcibly remove smaller individuals from preferred den sites, thereby altering the number of sub-legals in an area. Thus, fishermen may be targeting such high relief areas in the North(west) Islands region to catch larger, more valuable lobsters.

CASP data suggest the South has far more next year fishery recruits than either the North(west) Islands or North Coast regions. While the South experiences a high fishing effort, there seems to be ample number of lobsters that will replace harvested lobsters the following season. On the other hand, if there is a lack of sub-legal lobsters in the North(west) Islands, this region may be harvesting more lobsters than what is sustainable. However, based on the CASP data, the number of recruits may not be a good predictor of the legal CPUE in the following year. This may be due to depletion of the legal stock, as seen in sharp decline in CPUE as the season progresses mentioned earlier. The high CPUE in the first two weeks of the season supports a high number of recruits in the previous year. Alternatively, the growth rates used in this assessment may not be accurate for the South, as lobsters may exhibit smaller molt increments there. This is supported by a study in San Diego that found an annual growth rate of 3.3 mm (Hovel et al. 2015). If true, some of the recruits in this analysis for the South may not be entering the fishery in the next year.

The CASP data identified differences in sex ratios of legal lobster trapped among regions, with implications for two fishery parameters; trap vulnerability and reproductive capacity. While not all years were significant, both the North(west) Islands and North Coast regions showed a female bias in the legal catch in year two, indicating a higher trap vulnerability for legal female lobsters. If the trend of a female biased catch continues, it could result in a decrease in reproductive output as disproportionately more female lobsters are harvested and removed from the population in these regions. This impact could be greatest for the North(west) Islands region where legal lobsters may be contributing a large proportion of egg production, as suggested by the proportion of eggs produced per trap and the lack of sub-legal lobsters. Based on my findings and given that sex ratios are known to be highly variable (Lindberg 1955; Hovel and Neilson 2011; Hovel et al. 2015), continued collection of sex information for the catch will be necessary to determine if the female biased catch occurs very frequently. If so, this strongly suggests that the trap vulnerability parameter of the current fishery model should vary between sexes and be regionally-based.

While legal lobster sex ratio varied only for a select year, sub-legal lobsters were female biased in all regions for all years, except for the North(west) Islands in year one, suggesting additional implications regarding trap vulnerability and reproductive capacity. In particular, while this study did not include information on the condition of the sub-legal lobsters before or after release, handling stress (loss of appendages) has been shown to reduce fecundity in other species of spiny lobster (Melville- Smith and de Lestang 2007). Handling stress may have the greatest effect in the South, where sub-legals contribute the most to the reproductive output, as seen in the analysis of egg production per trap and at locations where females dominate the sub-legal catch. These effects would be most pronounced for next year recruits, as the escape ports restrict the sizes retained and handled.

Assessments of egg production suggest regional variation in reproductive capacity of the fished population, with greater egg production in the South compared to either the North Coast or North(west) Islands. This finding is heavily influenced by the large number of mature sub-legal lobsters in the South. These sub-legal lobsters are retained in the population and continue to contribute to reproductive output. Further, estimates of egg production are conservative in the South, as this region likely has a lower size at maturity (SAM) than used in this analysis. For example, egg-bearing lobsters as small as 53 mm CL have been reported off San Diego in the South region (Hovel et al. 2015; Hovel and Neilson 2011), while the smallest SAM reported in the North Coast region (Palos Verdes) was about

63 mm (Lindberg 1955). The variation in SAM is likely due to differences in temperature, as numerous studies of other lobster, including spiny lobster, have documented an earlier onset of maturity in warm water areas (Templeman 1936; Annala et al. 1980; Little and Watson 2005; Gardner et al. 2006).

Unlike the South, egg production in the North Coast and North(west) Islands is greatest in the legal fraction of the population. As a result an increase in fishing effort in these regions, to levels seen in the South, would reduce the regional reproductive output, particularly in the North(west) Islands. This lower reproductive output could eventually result in a reduction in lobster abundance depending on recruitment dynamics and the contribution of recruits from other regions which remains unclear with some studies suggesting high connectivity as evidenced by little genetic variation throughout its range (Garcia-Rodriguez and Perez-Enriquez 2004), and others indicating some potential for localized recruitment (Perez-Enriquez et al. 2001; Iacchei et al. 2013).

Implications for Management

It is important to recognize that the data collected through the CASP do not constitute a stock assessment, which would require intensive sampling across regions stratified by depth and habitat. Further, CASP data do not address the recreational fishery which also is likely impacting size structure and other aspects of the fishery. Rather, the CASP data provide information that can greatly improve the accuracy and supplement the type of information currently being collected for management via commercial landings receipts and logbook data. For example, CASP data can provide a direct measure of the CPUE reference point, which may be more accurate than estimates from logbook data.

Fishermen may estimate the number of traps serviced in the logbook, which directly affects calculations of CPUE. By contrast, CASP data are taken per trap, eliminating this error. Further, CASP fishermen undergo rigorous training and collect data using well-defined protocols that help reduce errors and eliminate the need for non-estimated data. Their collected data are also rigorously cross-checked by CASP scientists.

In addition to the questionable accuracy of trap counts, other errors have been noted in the logbook data. I found over 3,000 entries from the unedited logbook data had missing values (i.e., ID numbers, the number of traps pulled or number lobsters retained or released). Logbook data also contained many erroneous entries, for example 101 legal and 139 sub-legal lobsters were apparently retained from only 3 trap pulls and on the other end of the spectrum, only 89 lobsters were retained from 817 trap pulls. Separating logbook data into regions may increase the effect of these errors by decreasing sample size. For these reasons, CASP data are undoubtedly more accurate for determining CPUE, regionally-based or not, and overall may be more efficient as quality assurance and control of data requires far less time with lower chance of errors. Given its higher reliability, CASP CPUE data could be used to calibrate and if necessary apply a correction factor to the logbook CPUE.

CASP data can also inform the SPR reference point and may be more accurate than CDFW data (logbook/landings receipts). Estimates of the average weight of the catch – a variable used in calculations of SPR – from CDFW and CASP data were somewhat similar. For two regions, the South and North Coast regions, the numbers were nearly identical. Although not statistically significantly different (at $p = 0.05$) likely because of low power, the difference in average weight estimates from CDFW in the North(west) Islands region was nearly 18% larger than the CASP estimate (corresponding to 114 mm CL and 97 mm

CL respectively). A trapping study conducted around the Northern Channel Islands found an average size similar to that of the CASP data, ranging from 90 mm to 96 mm CL (Kay 2011). Kay (2011) also reported that lobsters in the marine protected areas averaged about 100 mm CL, which is smaller than the average size determined from the logbook/landing data. These data sets bring the accuracy of the CDFW-collected data into question for the North(west) Islands, and the calculations of SPR and potentially resulting management actions resulting from analysis of these data.

There are several issues that may contribute to errors in the average weight as determined from CDFW data. Most notably, are problems with matching logbook data to landings receipts (Neilson 2011). I found that matching individual landings receipt ID to the corresponding logbook ID revealed some average weights that were above the largest lobster ever caught and weights that were below the minimum legal size. Mismatching of data may be one explanation for the higher average weight in the North(west) Islands as there may be more than one logbook ID associated with a landings ID. Fishermen in the North(west) Islands region have to travel greater distances to their fishing ground, thus they may extend their trip duration to reduce fuel expenses. Hence, the lobsters sold to distributors may consist of multiple fishing days, associated to several logbook ID's but only a single landing receipt ID. Further, logbook ID's sometimes include several different CDFW block numbers, while the landing receipts only allow a single block number to be reported. Consequently this makes it impossible to determine the average weight for a single block. As average weight of the landed catch is used to determine the SPR reference point, errors in this value affect estimates of the reference point and the resulting management actions. While CDFW could eliminate the disconnect between the logbook and landing receipts by including the number of lobster that were weighed on the landing receipts, solving the issue of lobster from multiple blocks in the logbooks but only a single block in the landing receipts would require fishermen to separate their catch.

In addition to issues with the parameters used to calculate SPR, the CASP data indicate some potential shortcomings with the Parrish Cable Model (on which the CDFW currently bases its estimates of the SPR reference point). CASP data indicated regional differences in average size, and thus SPR among regions. Yet only a single SPR is currently considered in the harvest control rules (CDWF 2014). I applied the CASP-derived regional average weights to the Parrish Cable Model (v 7.2 E-K), and obtained SPR (proportion of eggs from a virgin stock) values of 0.28 in the South, 0.40 in the North Coast and 0.69 in the North(west) Islands. At present, the Parrish Cable Model does not consider these regional differences and estimates the SPR for all regions combined is around 0.45. In addition, the current model does not consider regional differences in other catch characteristics, such as sex ratios and the abundance of the sub-legal lobsters as they impact trap vulnerability model parameter and the reproductive output of the region. Further, the current SPR reference point neglects the contribution of larvae coming from Mexico, which may be substantial (Pringle 1986).

Lastly, the model would benefit from using individual measurements instead of average weights, as suggested by the recent scientific review of the FMP (Field et al. 2015). For example, the growth parameter in the model is based off carapace length, yet the landings receipts and logbook data only provide average weights. As a result, the model must convert average weight to average carapace length using a weight to length correlation that only explains 77% of the variability (Neilson 2011), thus this error is carried over into the model.

The current method of managing the fishery as a single area may not be able to detect regional variations in the reference points. If a reference point in one region is below the threshold, but if the fishery as a whole is above the threshold, no management action will be taken. Such a lack of action could potentially cause regional depletion of the stock. Likewise, some regions may benefit from added management, while other regions may be hindered by further restrictions.

Collectively, results from this study support area-based management that considers the spatial variation in fishery parameters among regions for the California spiny lobster fishery. Such a management strategy is used in several other lobster fisheries, including the *P. interruptus* fishery in Mexico, where area-based variation occurs (Acheson et al. 2000; SCS 2004; SAFMR 2006; Yandle 2006; Muñoz-Núñez 2009; GWADF 2012). In California, fishery models are based primarily on data from the Northern Channel Islands, Catalina Island and Palos Verdes. However, variation within the fishery, as seen in the CASP data, indicates that using information from one region may not be accurate for other regions. This is particularly true for areas such as the Southern California Bight where environmental factors vary among regions and subsequently may affect the parameters of the model. Numerous studies of decapods have shown, for example, an earlier onset of maturity in warmer water areas (Templeman 1936; Annala et al. 1980; Dugan et. al. 1991; Little and Watson 2005; Gardner et al. 2006). Further, the few studies of California spiny lobster growth rates also suggest variation (Odemar et al. 1975; Engle 1979; Kay 2011; Hovel et. al. 2015). Future research determining the spatial variation in egg production, growth, and size at maturity for lobster throughout the bight is critically needed, as these parameters will impact the outcome of fishery models. This is particularly true for measures of fecundity since egg counts in the California stock have only been done once on a few lobster (n=6) from a single location, nearly 100 years ago (Allen 1916). All subsequent studies refer to the size/fecundity relationship estimated from this limited sample.

Utility of a CASP for the California Spiny Lobster Fishery

The California lobster CASP has been a valuable method for collecting fishery-dependent data. While such data may not provide a direct measure of the overall population, they do provide invaluable information about the 'fished' population. It is important to remember this when interpreting the data. For example, the size distribution of the catch is influenced by the use of commercial lobster traps that have certain size entry funnels and escape ports. Lobsters larger than the entry funnel will not be captured in the traps, but likely occur in all regions as evident from sport diver observations and catches. In addition, small lobsters leave the trap via escape ports, as indicated by the sharp decline in the proportion of lobsters below 76.6 mm in the CASP data set. Likewise, because CASP data are collected only from October through January, the sizes and sex ratios may vary from those reported in fishery-independent studies. Nonetheless these data help assess the part of the lobster population that is being removed via the commercial fishery and impacts to reproductive capacity while also providing an indication of recruits that will be entering the fishery.

To properly manage a fishery, it is important to include multiple sources of data. While the CASP provides a cost-effective way to collect fishery-dependent essential fishery information for the commercial fishery, fishery-dependent data are also needed for the recreational fishery. Further, fishery-independent data too are needed to identify size distributions, sex ratios and other variables of the overall lobster population. Assessments of growth rates, fecundity, and settlement over the range of the fishery through additional studies will also enhance the ability to manage the fishery. Other fisheries, such as the New Zealand lobster fishery, supplement their collaborative sampling programs with multiple data sets to more accurately depict their fishery (Starr 2010).

Notably, the data obtained from the California lobster CASP provided timely, fishery-wide, essential information needed to enhance management. A recent scientific review panel called for such data for management of the fishery (Field et al. 2015). Not only have CASP data augmented the existing fisheries data, it also lead to the identification of gaps in the current model and in harvest control rules. CASP data could help strengthen proposed fisheries models by incorporating information on the sub-legal population and sex-specific trap vulnerabilities. This program also has helped address the California Marine Life Management Act requirement for the lobster FMP to use the best information available, and has provided a feasible protocol for collecting data to inform managers regarding the health of the stock. The long-term implementation of the CASP would allow managers to move to more sophisticate modeling approaches, with the ability to track the population and cohorts over time (Field et. al. 2015). This in turn should enhance management of the California spiny lobster fishery.

REFERENCES

1. Acheson, J.M., T. Stockwell and J.A. Wilson. 2000. Evolution of the Maine Lobster Co-Management. Maine Policy Review. 9(2):52–62.

2. Allen, B.M. 1916. Notes on the spiny lobster (*Panulirus interruptus*) of the California coast. University of California Publications in Zoology. 16(12):139-152.

3. Annala, J.H., J.L. McKoy, J.D. Booth and R.B. Pike. 1980. Size at the onset of sexual maturity in female *Jasus edwardsii* (Decapoda: P*alinuridae*) in New Zealand. New Zealand Journal of Marine and Freshwater Research. 14(3): 217-227

4. Barsky, K.C. 2001. California Spiny Lobster. In California's Living Marine Resources: A Status Report. California Department of Fish and Game. 98-100.

5. California Department of Fish and Wildlife. 2014. Draft Spiny Lobster Fishery Management Plan: Preliminary Public Draft. 116 p. Available at: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=91448&inline

6. Dugan, J.E., A.M. Wenner and D.M. Hubbard. 1991. Geographic variation in the reproductive biology of the sand crab Emerita analoga (Stimpson) on the California coast. Journal of Experimental Marine Biology and Ecology. 150(1): 63–81.

7. Engle, J. M. 1979. Ecology and growth of juvenile California spiny lobster, *Panulirus interruptus* (Randall). Doctoral dissertation, University of Southern California. 298 p.

8. Field, J. F., M. Comeau, R. Muller and P. Raimondi. 2015. Scientific review of the reference point thresholds prescribed in the draft Fishery Management Plan for the California Spiny Lobster (*Panulirus interruptus*). California Ocean Protection Council and the California Ocean Science Trust. 29 p.

9. García-Rodríguez, F.J. and R. Perez-Enriquez. 2006. Genetic differentiation of the California spiny lobster *Panulirus interruptus* (Randall, 1840) along the west coast of the Baja California Peninsula, Mexico. Marine Biology. 148(3):621-629.

10. Gardner, C., S.D. Frusher, N.S. Barrett, M. Haddon, and C.D. Buxton. 2006. Spatial variation in size at onset of maturity of female southern rock lobster *Jasus edwardsii* around Tasmania, Australia. Scientia Marina. 70(3):423-430.

11. Government of Western Australia Department of Fisheries (GWADF). 2012. Status Reports of the Fisheries and Aquatic Resources of Western Australia 2011/2012. http://www.fish.wa.gov.au/Documents/sofar/status_reports_of_the_fisheries_and_aquatic_resour ces_2011-12.pdf

12. Hovel, K.A. and D.J. Neilson. 2011. Movement and population size of lobsters in San Diego Bay. Final Report assembled for the San Diego Unified Port District. 34p.

13. Hovel, K.A., D.J. Neilson and E. Parnell. 2015. Baseline characterization of California spiny lobster (*Panulirus interruptus*) in the South Coast marine protected areas. California Sea Grant. Final report. 72p.

14. Iacchei, M., T. Ben-Horin, K.A. Selkoe, C.E. Bird, F.J. García-Rodríguez and R.J. Toonen. 2013. Combined analyses of kinship and FST suggest potential drivers of chaotic genetic patchiness in high gene-flow populations. Molecular Ecology. 22(13):3476–3494.

15. Johnson ME and H.J. Snook. 1927. Seashore animals of the Pacific Coast. University of California Publications in Zoology. 23:1-470

16. Johnson, M.W. 1960. The offshore drift of larvae of the California spiny lobster, *Panulirus interruptus*. CalCOFI Reports. 7:147–161

17. Kay, M.C. 2011. Community Based Fisheries Research on California Spiny Lobster (*Panulirus interruptus*) at the Santa Barbara Channel Islands. Ph.D. Dissertation, University of California Santa Barbara.

18. Koslow, J.A., L. Rogers-Bennett and D.J. Neilson. 2012. A time series of California spiny lobster (Panulirus interruptus) phyllosoma from 1951 to 2008 links abundance to warm oceanographic conditions in Southern California. CalCOFI Report. 53:132-139.

19. Lindbergh, R.G. 1955. Growth, population dynamics, and field behavior in the spiny lobster, *Panulirus interruptus* (Randall). University of California Publications in Zoology. 59:157-247.

20. Little S.A. and Watson, W.H. III. 2005. Differences in the size at maturity of female American lobsters, *Homarus americanus*, captured throughout the range of the offshore fishery. Journal of Crustacean Biology. 25(4):585-592.

21. Melville-Smith, R. and S. de Lestang. 2007. Changes in egg production of the western rock lobster (*Panulirus cygnus*) associated with appendage damage. Fishery Bulletin. 105(3):418-425.

22. Muñoz-Núñez, D. 2009. The Caribbean spiny lobster fishery in Cuba: An approach to sustainable fishery management. Master's of Science. Thesis, Duke University, Nicholas School of the Environment.

23. National Oceanic and Atmospheric Administration's National Centers For Environmental Information. 2015. https://www.nodc.noaa.gov/dsdt/cwtg/spac.html

24. National Oceanic and Atmospheric Administration's National Data Buoy Center. 2012. Southwest Inset Historical Marine Data. http://www.ndbc.noaa.gov/maps/southwest_inset_hist.shtml

25. Neilson, D.J. 2011. Assessment of the California Spiny Lobster (*Panulirus interruptus*). Final post technical review report, California Fish and Game Commission. 138p.

26. Odemar, M.W., R.R. Bell, C.W. Haugen and R.A. Hardy. 1975. Report on California spiny lobster, *Panulirus interruptus* (Randall) research with recommendations for management. Report to the State of California Resources Agency, Department of Fish and Wildlife. 98 pp.

27. Perez-Enriquez, R., A. Vega, S. Avila and J.L. Sandoval. 2001. Population genetics of red spiny lobster (*Panulirus interruptus*) along the Baja California Peninsula, Mexico. Marine and Freshwater Research. 52(8): 1541–1549.

28. Pringle, J. D. 1986. California spiny lobster (*Panulirus interruptus*) larval retention and recruitment: a review and synthesis. Canadian Journal of Fisheries and Aquatic Sciences. 43(11):2142–2152.

29. Schmitt, W.L. 1921. The Marine decapod crustacean of California. Berkeley, University of California Press Publications Zoology. 23:1-470.

30. Scientific Certification Systems. 2004. An MSC Assessment of the Red Rock Lobster Fishery, Baja California, Mexico. Final Report. Scientific Certification Systems, Inc., Emeryville, California, USA. 206p.

31. South Australia Fishery Management (Rock Lobster Fisheries) Regulations. 2006. http://legislation.sa.gov.au/lz/c/r/fisheries%20management%20%28rock%20lobster %20fis heries%29%20regulations%202006.aspx.

32. Starr, P. 2010. Fisher-collected sampling data: lessons from the New Zealand experience. Marine and Coastal Fisheries. 2(1):47-59.

33. State of Hawaii Division of Aquatic Resources. 2015. How to determine sex of regulated invertebrates. http://dlnr.hawaii.gov/dar/fishing/fishing-regulations/marine-invertebrates/how-to-determine-sex-of-regulated-invertebrates/

34. Templeman, W. 1936. Local differences in the life history of the lobster (Homarus americanus) on the coast of the Maritime Provinces of Canada. Journal of the Biological Board of Canada. 2(1):876-901.

35. Wilson, R. 1948. A review of the southern California spiny lobster fishery. California Fish and Game. 34:71-80.

36. Yandle, T. 2006. Sharing natural resource management responsibility: Examining the New Zealand Rock Lobster co-management experience. Policy Sciences. 39(3):249-278.

Table 1 Percentage of commercial trap sizes used during the study in three regions: South, North Coast, and North(west) Islands. Includes all three years

Trap Size (meters)	% South (n=78)	% North Coast (n=48)	% North(west) Islands (n=22)
0.91 x 0.61	19.2	4.2	0.0
0.91 x 0.71	61.6	29.1	22.7
1.02 x 0.71	5.1	16.7	50.0
1.22 x 0.91	0.0	27.1	27.3
Other	14.1	22.9	0.0

Table 2: Percentage of bait types used during the study in three regions: South, North Coast, and North(west) Islands. Includes all three years.

Bait Type	% South (n=83)	% North Coast (n=58)	% North(west) Islands (n=23)
Mackerel	2.4	60.3	56.5
Salmon	59.1	39.7	34.8
Salmon and Mackerel	28.9	0.0	0.0
Tuna	6.0	0.0	0.0
Other	3.6	0.0	8.7

Table 3 Percentage soak times used during the study in three regions: South, North Coast, and North(west) Islands. Includes all three years. If more than one soak time was used in a sample, each was included separately.

Soak Time (days)	% South (n=85)	% North Coast (n=58)	% North(west) Islands (n=25)
1	4.7	15.5	12.0
2	22.4	15.5	12.0
3	27.1	32.8	36.0
4	36.4	32.8	32.0
>4	9.4	3.4	8.0

Table 4: Data used in analyses and collected by the Collaborative At-Sea Sampling Program (CASP) for the California spiny lobster fishery from October through January for three consecutive years.

Sampling Effort	Year One 2012-2013	Year Two 2013-2014	Year Three 2014-2015	Total
Fishermen	8	13	14	20*
Trips Sampled	20	69	75	164
Traps Sampled	3,096	4,137	4,238	11,471
Lobsters Counted	7,438	10,942	9,948	28,328
Lobsters Sub-sampled	890	4,276	4,292	9,458

* Fishermen that participated in more than one seasons were only counted once

Table 5: Comparison of mean catch per trap of legal and sub-legal lobster among three regions; South, North Coast, North(west) Islands. Mixed model ANOVA with year as the random variable and region as the fixed variable. Degrees of freedom (df), mean square (ms), F value and P value.

Overall difference in mean CPUE among regions

Source	df	ms	F value	P value
Legal				
Region	2.0	0.92	0.36	0.7156
Year	2.0	1.49	0.60	0.5906
Region*Year	4.0	2.75	7.57	<0.0001
Error (Region)	4.1	2.54		
Error (Year)	4.1	2.49		
Error (Region*Year)	11462.0	0.36		
Sub-legal				
Region	2.0	1693.25	91.61	0.0004
Year	2.0	18.48	1.02	0.4373
Region*Year	4.0	20.22	25.61	<0.0001
Error Region	4.0	18.48		
Error Year	4.0	18.09		
Error (Region*Year)	11462.0	0.79		

Table 6: Annual comparison of mean catch per trap of legal and sub-legal lobster among three regions; South, North Coast, North(west) Islands. One-way ANOVA with Tukey-Kramer post-hoc analyses. Degrees of freedom (df), mean square (ms), F value and P value. Numbers in parentheses are mean CPUE estimates.

Source	df	ms	F	P value
Legal				
Year 1	2	0.72	2.07	0.1264
North Coast (0.47) vs South (0.54)				>0.05
North Coast (0.47) vs North(west) Islands (0.46)				>0.05
South (0.54) vs North(west) Islands (0.46)				>0.05
Year 2	2	7.14	19.98	**<0.0001**
North Coast (0.66) vs South (0.42)				**<0.05**
North Coast (0.66) vs North(west) Islands (0.54)				**<0.05**
South (0.42) vs North(west) Islands (0.54)				>0.05
Year 3	2	0.60	1.58	0.206
North Coast (0.60) vs South (0.50)				>0.05
North Coast (0.60) vs North(west) Islands (0.61)				>0.05
South (0.50) vs North(west) Islands (0.61)				>0.05
Sub-Legal				
Year 1	2	639.86	746.30	**<0.0001**
North Coast (1.15) vs South (4.15)				**<0.05**
North Coast (1.15) vs North(west) Islands (0.21)				**<0.05**
South (4.15) vs North(west) Islands (0.21)				**<0.05**
Year 2	2	832.63	1095.1	**<0.0001**
North Coast (0.88) vs South (4.02)				**<0.05**
North Coast (0.88) vs North(west) Islands (0.25)				**<0.05**
South (4.01) vs North(west) Islands (0.25)				**<0.05**
Year 3	2	438.90	571.4	**<0.0001**
North Coast (0.99) vs South (2.73)				**<0.05**
North Coast (0.99) vs North(west) Islands (0.15)				**<0.05**
South (2.73) vs North(west) Islands (0.15)				**<0.05**

Table 7: Annual comparison of lobster size distribution among three regions; South, North Coast, North(west) Islands. Chi-square with contingency table. Degrees of freedom (df), Chi-square value (x^2), and p value for each year.

Year	df	χ^2	p-value
1	12	477	**<0.0001**
2	12	1140	**<0.0001**
3	12	1100	**<0.0001**

Table 8: Comparison of mean size of legal and sub-legal lobster among three regions; South, North Coast, North(west) Islands. Mixed model ANOVA with year as the random variable and region as the fixed variable. Degrees of freedom (df), mean square (ms), F value and P value

Source	df	ms	F value	P value
Legal				
Region	2.0	44.67	24.80	0.0036
Year	2.0	1.78	0.69	0.5519
Region*Year	4.0	2.71	9.35	<0.0001
Error (Region)	4.5	1.79		
Error (Year)	4.0	2.58		
Error (Region*Year)	3146.0	2.58		
Sub-legal				
Region	2.0	0.05	0.21	0.8210
Year	2.0	0.71	3.33	0.1088
Region*Year	4.0	0.38	5.51	0.0002
Error Region	5.0	0.26		
Error Year	5.8	0.21		
Error (Region*Year)	6294.0	0.07		

Table 9: Annual comparison of mean size of legal and sub-legal lobster among three regions; South, North Coast, North(west) Islands. One-way ANOVA with Tukey-Kramer post-hoc analyses. Degrees of freedom (df), mean square (ms), F value and P value. Numbers in parenthesis are mean carapace length estimates in millimeters.

Source	df	ms	F	P value
Legal				
Year 1	2	11.10	43.86	**<0.0001**
North Coast (86.3) vs South (86.0)				>0.05
North Coast (86.3) vs North(west) Islands (98.5)				**<0.05**
South (86.0) vs North(west) Islands (98.5)				**<0.05**
Year 2	2	17.82	59.08	**<0.0001**
North Coast (91.6) vs South (84.8)				**<0.05**
North Coast (91.6) vs North(west) Islands (94.6)				**<0.05**
South (84.8) vs North(west) Islands (94.6)				**<0.05**
Year 3	2	37.19	131.45	**<0.0001**
North Coast (90.9) vs South (86.0)				**<0.05**
North Coast (90.9) vs North(west) Islands (96.7)				**<0.05**
South (86.0) vs North(west) Islands (96.7)				**<0.05**
Sub-Legal				
Year 1	2	0.26	3.90	**0.0207**
North Coast (77.4) vs South (78.6)				**<0.05**
North Coast (77.4) vs North(west) Islands (77.6)				>0.05
South (78.6) vs North(west) Islands (77.6)				>0.05
Year 2	2	0.41	6.23	**0.0020**
North Coast (78.8) vs South (78.2)				**<0.05**
North Coast (78.8) vs North(west) Islands (78.6)				>0.05
South (78.2) vs North(west) Islands (78.6)				>0.05
Year 3	2	0.47	6.48	**0.0015**
North Coast (78.9) vs South (78.6)				>0.05
North Coast (78.9) vs North(west) Islands (80.3)				**<0.05**
South (78.6) vs North(west) Islands (80.3)				**<0.05**

Table 10: Comparison of mean weight of legal lobster among three regions; South, North Coast, North(west) Islands. Mixed model ANOVA with year as the random variable and region as the fixed variable. Degrees of freedom (df), mean square (ms), F value and P value.

Source	df	ms	F value	P value
Region	2.0	2.61	23.14	0.0041
Year	2.0	0.11	0.66	0.5629
Region*Year	4.0	0.17	9.10	<0.0001
Error (Region)	4.6	0.11		
Error (Year)	4.0	0.16		
Error (Region*Year)	3146.0	0.02		

Table 11: Annual comparison of mean weight of legal lobsters among three regions; South, North Coast, North(west) Islands. One-way ANOVA with Tukey-Kramer post-hoc analyses. Degrees of freedom (df), mean square (ms), F value and P value. Numbers in parenthesis are legal lobster weight estimates in kilograms

Source	df	ms	F	P value
Year 1	2	0.65	37.95	**<0.0001**
North Coast (0.67) vs South (0.67)				>0.05
North Coast (0.67) vs North(west) Islands (0.97)				**<0.05**
South (0.67) vs North(west) Islands (0.97)				**<0.05**
Year 2	2	1.01	52.34	**<0.0001**
North Coast (0.80) vs South (0.64)				**<0.05**
North Coast (0.80) vs North(west) Islands (0.87)				**<0.05**
South (0.64) vs North(west) Islands (0.87)				**<0.05**
Year 3	2	2.23	122.11	**<0.0001**
North Coast (0.78) vs South (0.67)				**<0.05**
North Coast (0.78) vs North(west) Islands (0.97)				**<0.05**
South (0.67) vs North(west) Islands (0.97)				**<0.05**

Table 12: Comparison of biomass per trap of legal, sub-legal and total (legal and sub-legal) lobster among three regions; South, North Coast, North(west) Islands. Mixed model ANOVA with year as the random variable and region as the fixed variable. Degrees of freedom (df), mean square (ms), F value and P value.

Source	df	ms	F value	P value
Legal				
Region	2.0	7.25	3.07	0.1535
Year	2.0	1.43	0.62	0.5832
Region*Year	4.0	2.57	9.25	<0.0001
Error (Region)	4.1	2.36		
Error (Year)	4.1	2.31		
Error (Region*Year)	11462.0	0.28		
Sub-legal				
Region	2.0	891.30	91.26	0.0004
Year	2.0	9.79	1.02	0.4366
Region*Year	4.0	10.68	25.53	<0.0001
Error Region	4.0	9.77		
Error Year	4.0	9.56		
Error (Region*Year)	11462.0	0.42		
Total				
Region	2.0	548.68	89.29	0.0004
Year	2.0	7.97	1.32	0.3604
Region*Year	4.0	6.69	12.13	<0.0001
Error (Region)	4.1	6.15		
Error (Year)	4.1	6.02		
Error (Region*Year)	11462.0	0.55		

Table 13: Annual comparison of biomass per trap of legal, sub-legal and total (legal and sub-legal) lobster among three regions; South, North Coast, North(west) Islands. One-way ANOVA with Tukey-Kramer post-hoc analyses. Degrees of freedom (df), mean square (ms), F value and P value. Numbers in parenthesis are mean weight per trap estimates in kilograms.

Source	df	ms	F	P value
Legal				
Year 1	2	0.19	3.00	0.0500
North Coast (0.37) vs South (0.36)				>0.05
North Coast (0.37) vs North(west) Islands (0.42)				>0.05
South (0.36) vs North(west) Islands (0.42)				>0.05
Year 2	2	9.02	33.00	**<0.0001**
North Coast (0.52) vs South (0.28)				**<0.05**
North Coast (0.52) vs North(west) Islands (0.50)				>0.05
South (0.28) vs North(west) Islands (0.50)				**<0.05**
Year 3	2	4.01	14.14	**<0.0001**
North Coast (0.47) vs South (0.33)				>0.05
North Coast (0.47) vs North(west) Islands (0.56)				**<0.05**
South (0.33) vs North(west) Islands (0.56)				**<0.05**
Sub-Legal				
Year 1	2	337.03	742.01	**<0.0001**
North Coast (0.62) vs South (2.19)				**<0.05**
North Coast (0.62) vs North(west) Islands (0.12)				**<0.05**
South (2.19) vs North(west) Islands (0.12)				**<0.05**
Year 2	2	438.20	1086.85	**<0.0001**
North Coast (0.47) vs South (2.12)				**<0.05**
North Coast (0.47) vs North(west) Islands (0.13)				**<0.05**
South (2.12) vs North(west) Islands (0.13)				**<0.05**
Year 3	2	230.81	567.05	**<0.0001**
North Coast (0.53) vs South (1.44)				**<0.05**
North Coast (0.53) vs North(west) Islands (0.08)				**<0.05**
South (1.44) vs North(west) Islands (0.08)				**<0.05**
Total				
Year 1	2	232.39	387.54	**<0.0001**
North Coast (0.98) vs South (2.55)				**<0.05**
North Coast (0.98) vs North(west) Islands (0.54)				**<0.05**
South (2.55) vs North(west) Islands (0.54)				**<0.05**
Year 2	2	254.48	488.16	**<0.0001**
North Coast (0.99) vs South (2.40)				**<0.05**
North Coast (0.99) vs North(west) Islands (0.63)				**<0.05**
South (2.40) vs North(west) Islands (0.63)				**<0.05**
Year 3	2	129.18	236.42	**<0.0001**
North Coast (1.00) vs South (1.77)				**<0.05**
North Coast (1.00) vs North(west) Islands (0.64)				**<0.05**
South (1.77) vs North(west) Islands (0.64)				**<0.05**

Table 14: Comparison of the number of next year fishery recruits per trap among three regions; South, North Coast, North(west) Islands. Mixed model ANOVA with year as the random variable and region as the fixed variable. Degrees of freedom (df), mean square (ms), F value and P value

Source	df	ms	F value	P value
Region	2.0	1364.08	105.53	0.0003
Year	2.0	9.55	0.76	0.5264
Region*Year	4.0	14.13	22.46	<0.0001
Error (Region)	4.0	12.93		
Error (Year)	4.0	12.65		
Error (Region*Year)	11462.0	0.63		

Table 15: Annual comparison of the number of next year fishery recruits among three regions; South, North Coast, North(west) Islands. One-way ANOVA with Tukey-Kramer post-hoc analyses. Degrees of freedom (df), mean square (ms), F value and P value. Numbers in parenthesis are mean number of next year recruits per trap estimates.

Source	df	ms	F	P value
Year 1	2	540.94	797.96	**<0.0001**
North Coast (0.79) vs South (3.40)				**<0.05**
North Coast (0.79) vs North(west) Islands (0.14)				**<0.05**
South (3.40) vs North(west) Islands (0.14)				**<0.05**
Year 2	2	633.49	1074.67	**<0.0001**
North Coast (0.70) vs South (3.09)				**<0.05**
North Coast (0.70) vs North(west) Islands (0.19)				**<0.05**
South (3.09) vs North(west) Islands (0.19)				**<0.05**
Year 3	2	350.44	554.4	**<0.0001**
North Coast (0.83) vs South (2.22)				**<0.05**
North Coast (0.83) vs North(west) Islands (0.15)				**<0.05**
South (2.22) vs North(west) Islands (0.15)				**<0.05**

Table 16: Annual comparison of CASP sex ratios among regions of legal and sub-legal lobsters. Chi-square with contingency table analyses. Degrees of freedom (df), Chi-square value and p value for each year.

Source	df	χ^2	p-value
Legal			
Year 1	2	0.52	0.7694
Year 2	2	17.52	**0.0002**
Year 3	2	0.34	0.8443
Sub-legal			
Year 1	2	46.26	**<0.0001**
Year 2	2	56.07	**<0.0001**
Year 3	2	189.00	**<0.0001**

Table 17: Annual comparison of sex ratio from CASP to the expected 50:50 sex ratio of legal and sub-legal lobsters. Chi-square analyses. Degrees of freedom (df), Chi-square value and p value for each year. Numbers in parentheses are the percent female for each region.

Source	df	χ^2	P value
Legal			
Year 1			
South (54.4)	1	0.53	0.4669
North Coast (58.5)	1	1.81	0.1790
North(west) Islands (52.5)	1	0.25	0.6153
Year 2			
South (47.1)	1	0.76	0.3840
North Coast (56.0)	1	12.27	0.0005
North(west) Islands (64.1)	1	31.68	0.0001
Year 3			
South (51.2)	1	0.24	0.6231
North Coast (53.0)	1	2.32	0.1281
North(west) Islands (52.7)	1	1.10	0.2945
Sub-legal			
Year 1			
South (84.4)	1	241.14	0.0001
North Coast (67.5)	1	14.04	0.0002
North(west) Islands (40.0)	1	1.20	0.2733
Year 2			
South (82.0)	1	731.08	0.0001
North Coast (74.5)	1	198.60	0.0001
North(west) Islands (60.0)	1	7.00	0.0082
Year 3			
South (84.7)	1	879.55	0.0001
North Coast (67.6)	1	48.93	0.0001
North(west) Islands (60.9)	1	14.09	0.0002

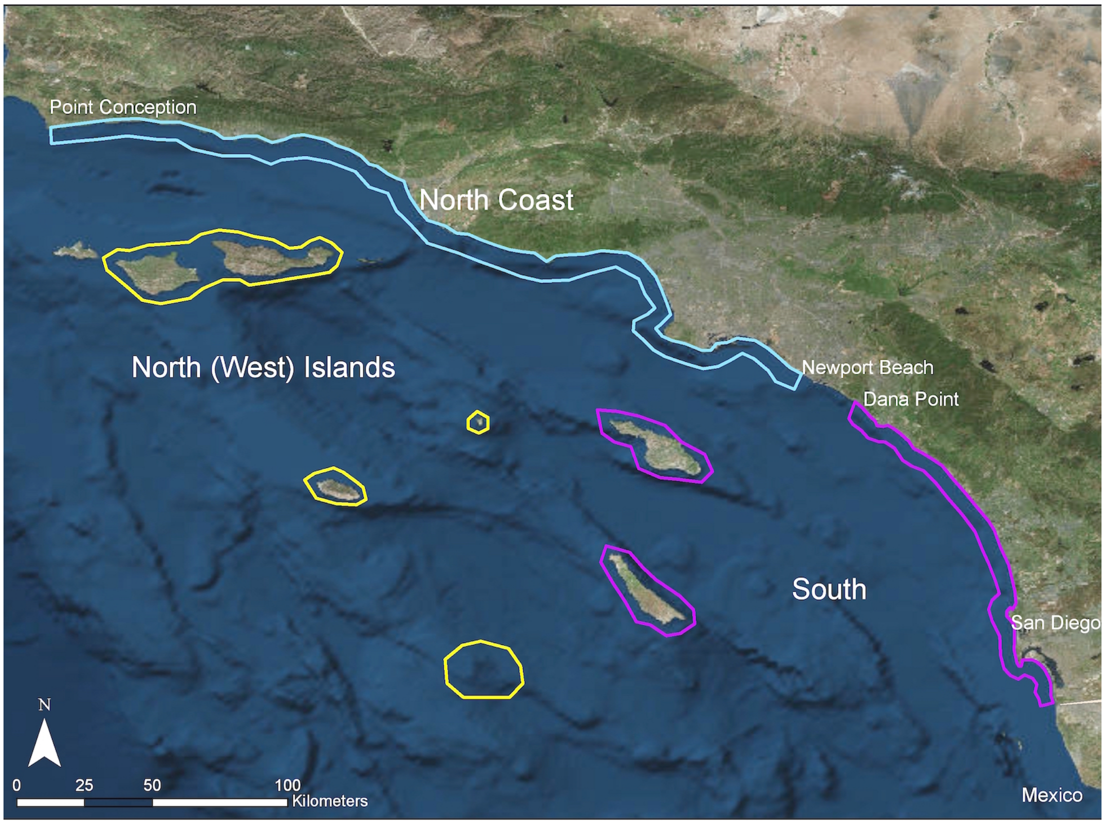
Table 18: Comparison of egg produced per trap by legal, sub-legal and total (legal and sub-legal) lobsters among three regions; South, North Coast, North(west) Islands. Mixed model ANOVA with year as the random variable and region as the fixed variable. Degrees of freedom (df), mean square (ms), F value and P value.

Source	df	ms	F value	P value
Total				
Region	2.0	1.04E+08	121.91	0.0002
Year	2.0	2.29E+06	2.74	0.1756
Region*Year	4.0	9.27E+05	9.39	<0.0001
Error (Region)	4.1	8.54E+05		
Error (Year)	4.1	8.37E+05		
Error (Region*Year)	11462.0	9.88E+04		
Legal				
Region	2.0	2.56E+06	5.29	0.0738
Year	2.0	2.93E+05	0.62	0.5826
Region*Year	4.0	5.26E+05	10.82	<0.0001
Error (Region)	4.1	4.84E+05		
Error (Year)	4.1	4.74E+05		
Error (Region*Year)	11462.0	4.87E+04		
Sub-legal				
Region	2.0	1.78E+08	129.4	0.0002
Year	2.0	1.80E+06	1.34	0.3578
Region*Year	4.0	1.50E+06	20.38	<0.0001
Error Region	4.0	1.37E+06		
Error Year	4.0	1.34E+06		
Error (Region*Year)	11462.0	7.36E+04		

Table 19: Annual comparison of the number of eggs produced per trap by legal, sub-legal and total (legal and sub-legal) lobster among three regions; South, North Coast, North(west) Islands. One-way ANOVA with Tukey-Kramer post-hoc analyses. Degrees of freedom (df), mean squared (ms), F value and P value. Numbers in parentheses are the estimated number of eggs per trap, shown in 1,000's of eggs.

Source	df	ms	F	P value
Legal				
Year 1	2	2.06E+05	4.24	**0.0145**
North Coast (71.3) vs South (58.6)				>0.05
North Coast (71.3) vs North(west) Islands (77.9)				>0.05
South (58.6) vs North(west) Islands (77.9)				**<0.05**
Year 2	2	3.07E+06	61.85	**<0.0001**
North Coast (96.3) vs South (39.2)				**<0.05**
North Coast (96.3) vs North(west) Islands (111.2)				>0.05
South (39.2) vs North(west) Islands (111.2)				**<0.05**
Year 3	2	8.81E+05	18.39	**<0.0001**
North Coast (82.4) vs South (50.6)				**<0.05**
North Coast (82.4) vs North(west) Islands (103.4)				**<0.05**
South (50.6) vs North(west) Islands (103.4)				**<0.05**
Sub-Legal				
Year 1	2	6.92E+07	868.31	**<0.0001**
North Coast (95.1) vs South (414.1)				**<0.05**
North Coast (95.1) vs North(west) Islands (10.6)				**<0.05**
South (414.1) vs North(west) Islands (10.6)				**<0.05**
Year 2	2	8.33E+07	1165.94	**<0.0001**
North Coast (79.7) vs South (389.7)				**<0.05**
North Coast (79.7) vs North(west) Islands (18.3)				**<0.05**
South (389.7) vs North(west) Islands (18.3)				**<0.05**
Year 3	2	4.82E+07	676.61	**<0.0001**
North Coast (74.5) vs South (273.2)				**<0.05**
North Coast (74.5) vs North(west) Islands (13.2)				**<0.05**
South (273.2) vs North(west) Islands (13.2)				**<0.05**
Total				
Year 1	2	4.64E+07	431.73	**<0.0001**
North Coast (166.4) vs South (472.7)				**<0.05**
North Coast (166.4) vs North(west) Islands (88.5)				**<0.05**
South (472.7) vs North(west) Islands (88.5)				**<0.05**
Year 2	2	4.34E+07	454.1	**<0.0001**
North Coast (176.0) vs South (428.9)				**<0.05**
North Coast (176.0) vs North(west) Islands (129.5)				**<0.05**
South (428.9) vs North(west) Islands (129.5)				**<0.05**
Year 3	2	2.72E+07	284.78	**<0.0001**
North Coast (156.9) vs South (323.8)				**<0.05**
North Coast (156.9) vs North(west) Islands (116.6)				**<0.05**
South (323.8) vs North(west) Islands (116.6)				**<0.05**

Figure 1: Three biogeographically distinct regions with varying parameters in the California spiny lobster fishery; South (purple), North Coast (blue), North(west) Islands (yellow).



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus

Figure 2: Mean (S.E.) number of (A) legal and (B) sub-legal lobsters caught per trap (CPUE, catch per unit effort) from three regions, over three years, within the Southern California Bight; South, North Coast, and North(west) Islands, as well as all regions combined. Bars with similar letters do not significantly differ (p-value ≥ 0.05). Numbers in parentheses are the number of traps sampled in each region for all years combined.

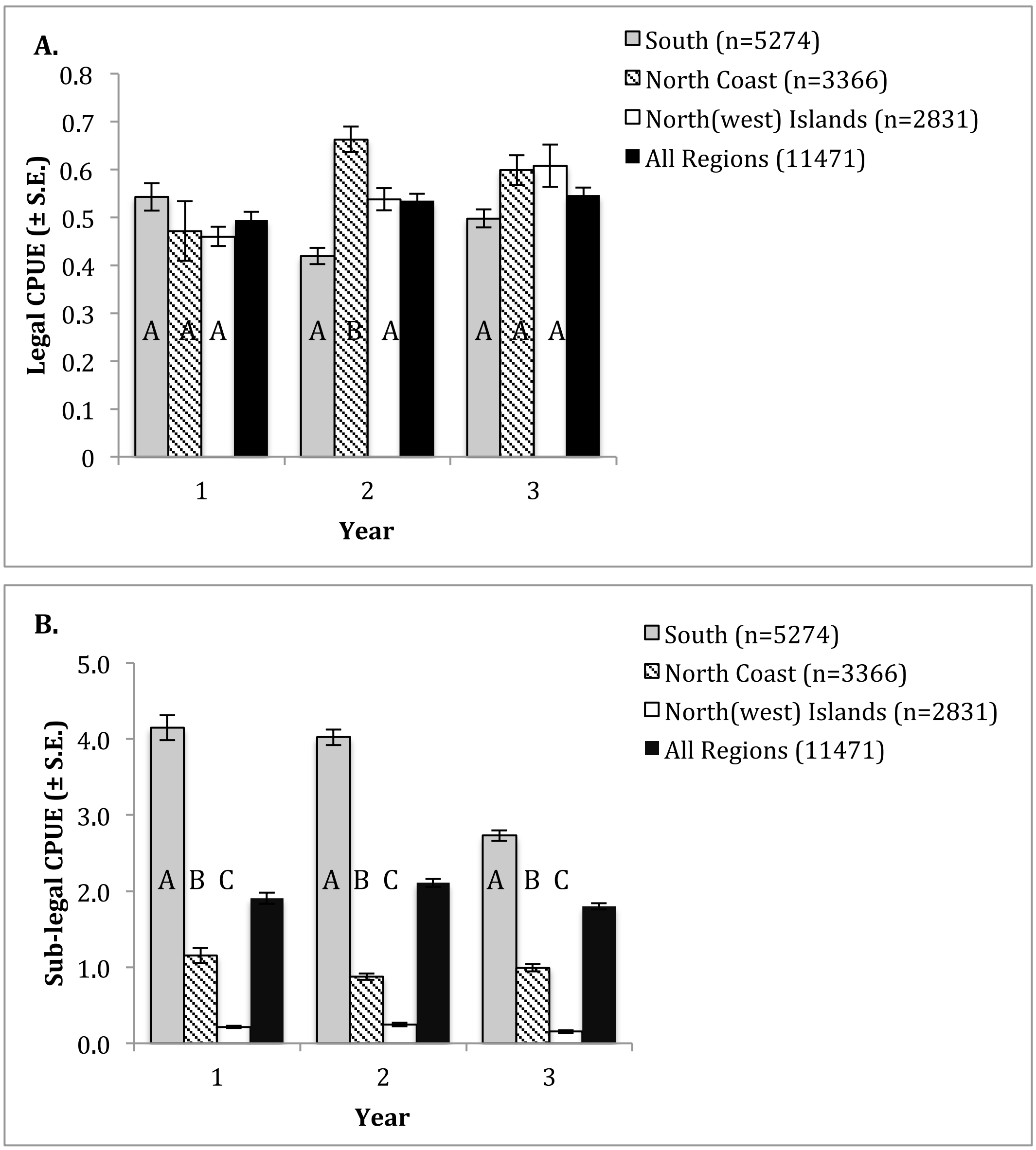


Figure 3: Size distribution of lobsters caught in commercial traps within the Southern California Bight; South, North Coast, North(west) Islands. A. Year 1 of CASP (2012-2013). B. Year 2 of CASP (2013-2014). C. Year 3 of CASP (2014-2015). Sub-legal lobsters are to the left of the dashed line and legal lobsters are to the right. Numbers in parentheses are the number of lobsters subsampled in each region.

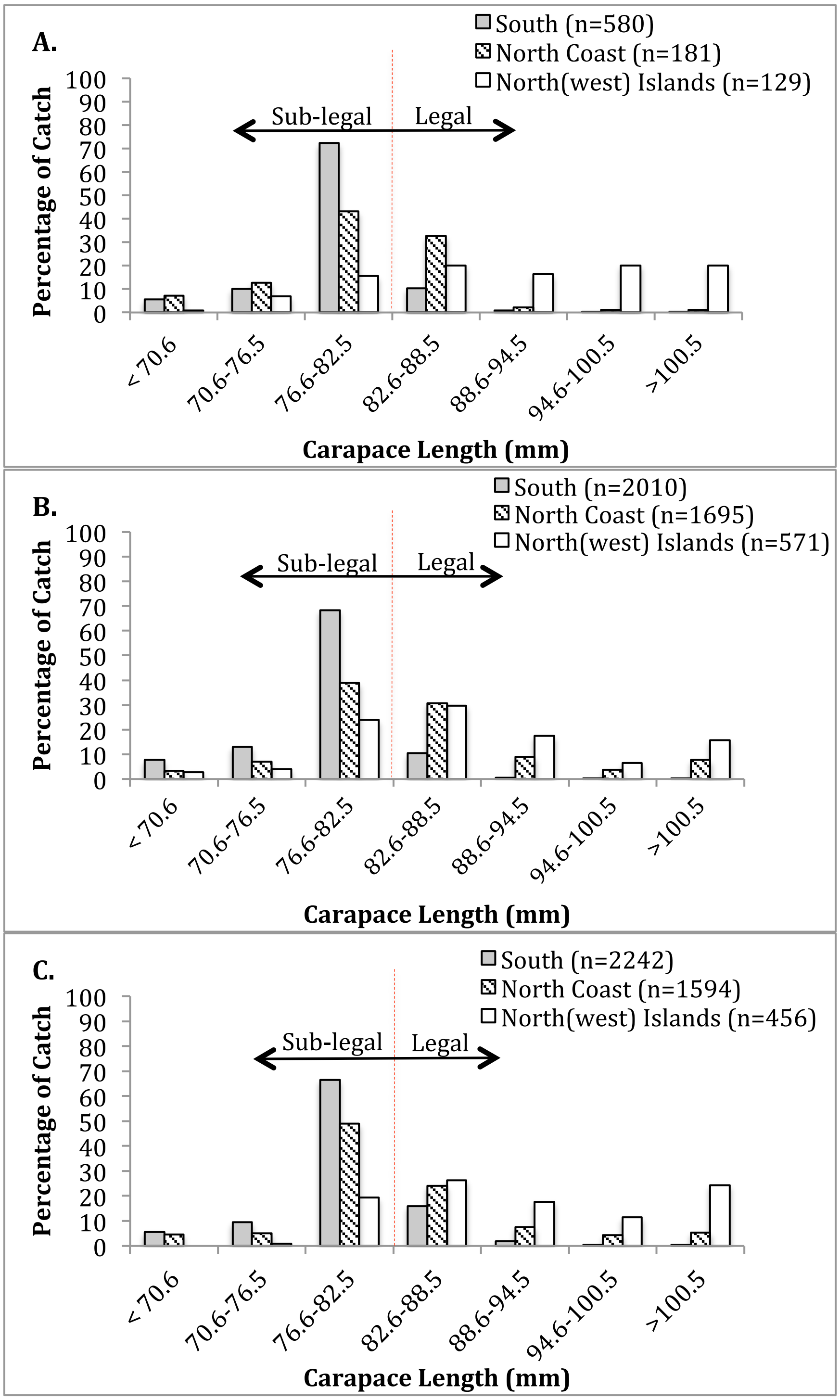


Figure 4: Mean (S.E.) carapace length of (A) legal and (B) sub-legal lobsters caught in commercial traps from three regions, over three years, within the Southern California Bight; South, North Coast, and North(west) Islands. Bars with similar letters do not significantly differ (p-value ≥ 0.05). Numbers in parentheses are the number of lobsters subsampled in each region for all years combined.

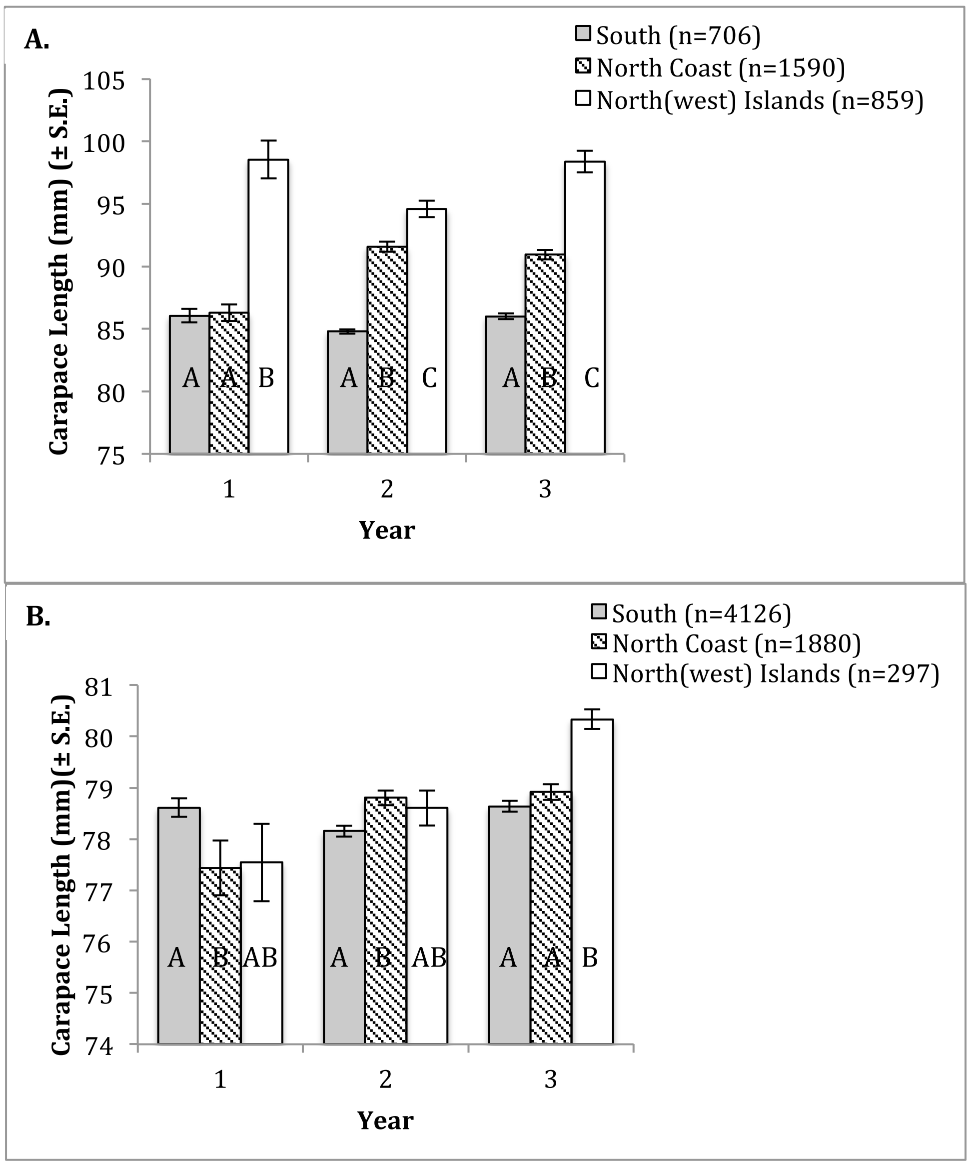


Figure 5: Mean (S.E.) weight of the legal catch for three regions, over three years, within the Southern California Bight; South, North Coast, and North(west) Islands, as well as all regions combined. Bars with similar letters do not significantly differ (p-value ≥ 0.05). Numbers in parentheses are the number of lobsters subsampled in each region for all years combined.

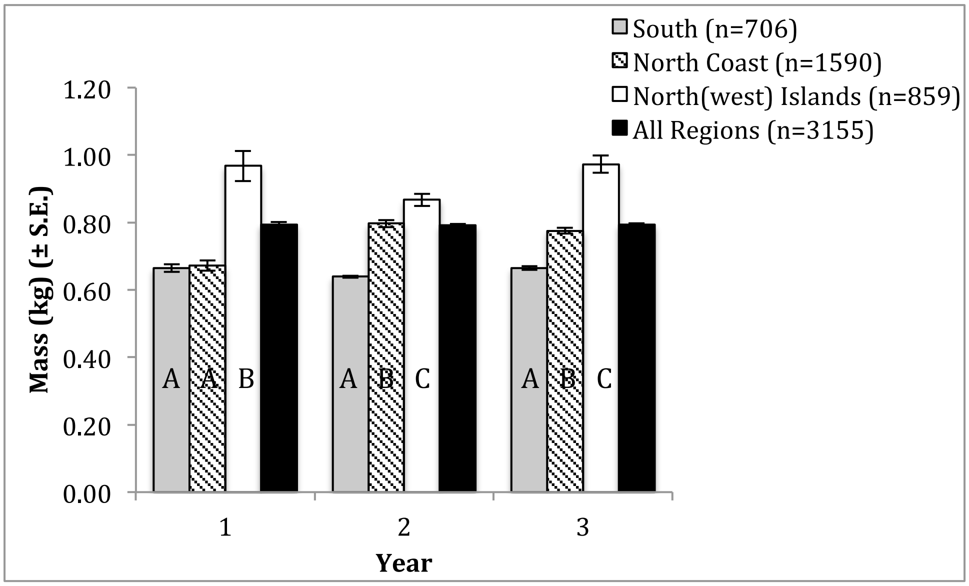


Figure 6: Mean (S.E.) biomass per trap in kilograms of (A) legal, (B) sub-legal, and (C) total (legal and sub-legal) lobsters from three derived regions within the Southern California Bight; South, North Coast, and North(west) Islands. Shown for three years. Bars with similar letters do not significantly differ (p-value ≥ 0.05). Numbers in parentheses are the number of lobsters subsampled in each region for all years combined.

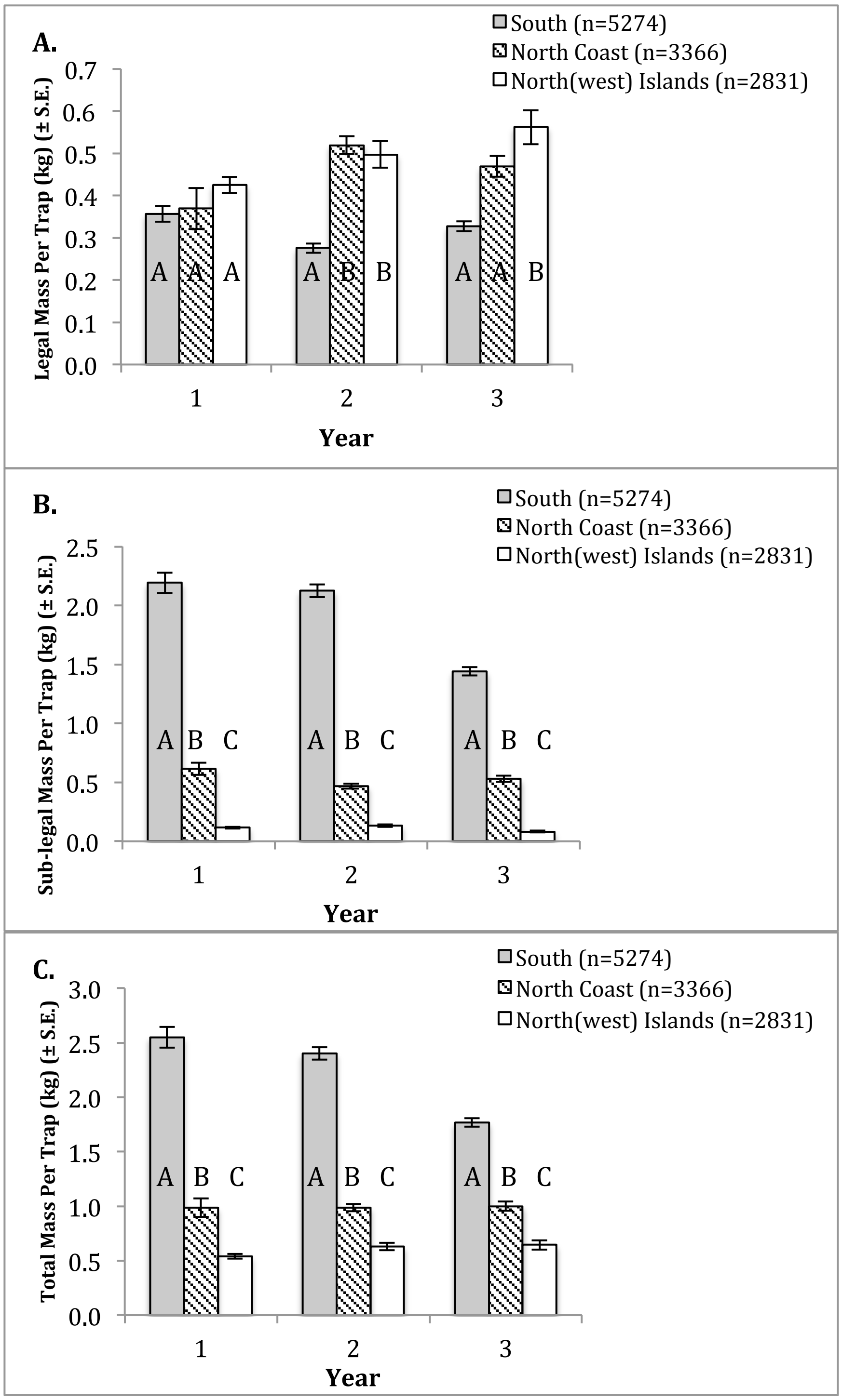


Figure 7: Percent of the sub-legal catch that will enter the fishery the following year (legal-1) from three regions, over three years, within the Southern California Bight; South, North Coast, and North(west) Islands. Numbers in parentheses are the number of sub-legal lobsters subsampled in each region for all years combined

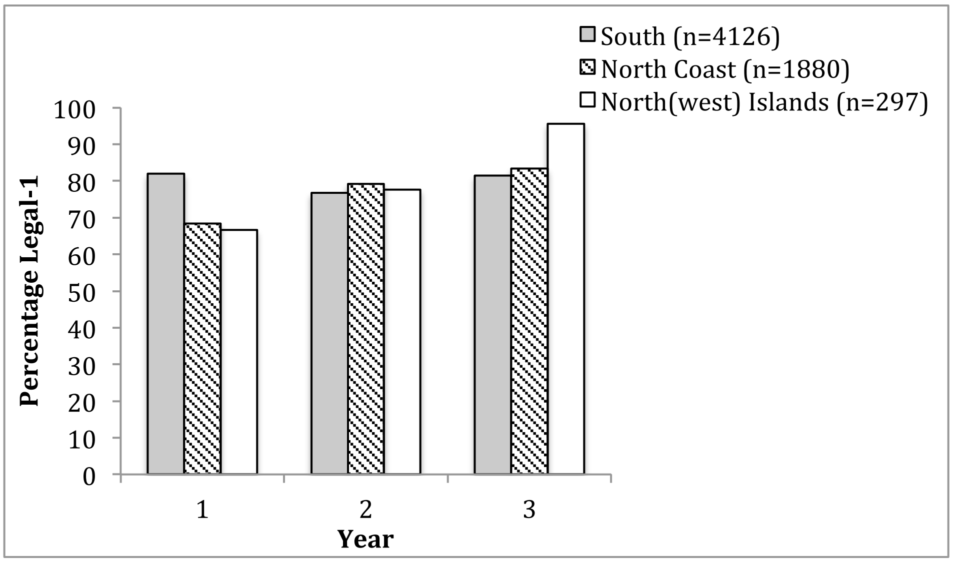


Figure 8: The mean (S.E.) number of lobster per trap that will enter the fishery the following year (legal-1) for three regions, over three years, within the Southern California Bight; South, North Coast, and North(west) Islands. Bars with similar letters do not significantly differ (p-value ≥ 0.05). Estimate based on a 6mm growth rate and the legal size (82.5 mm). Numbers in parentheses are the number of traps sampled in each region for all years combined.

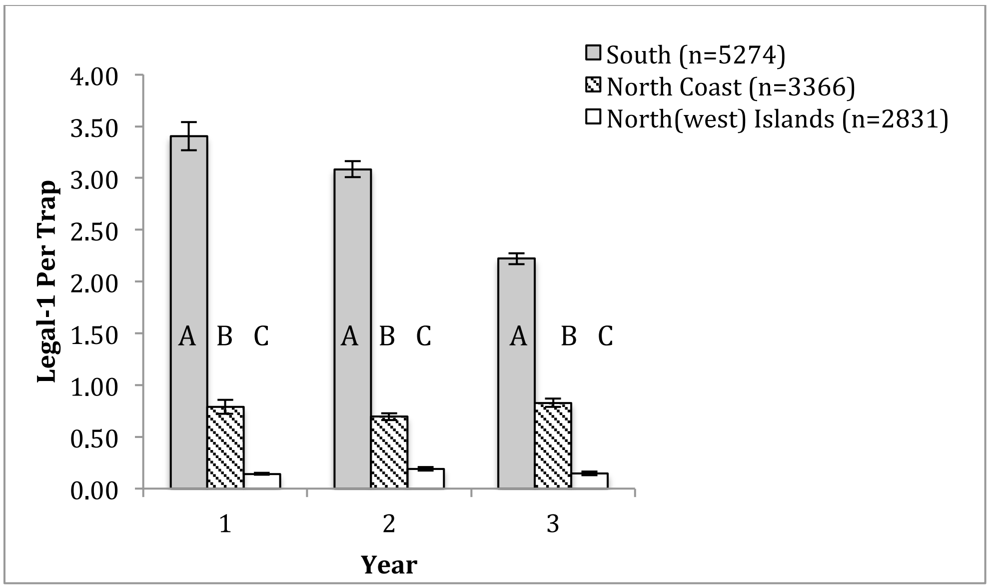


Figure 9: The sex ratio of (A) legal and (B) sub-legal lobsters of three regions, over three years, within the Southern California Bight; South, North Coast, and North(west) Islands Shown percent female. Numbers in parentheses are the number of lobsters subsampled in each region for all years combined. The line represents the 50:50 ratio.

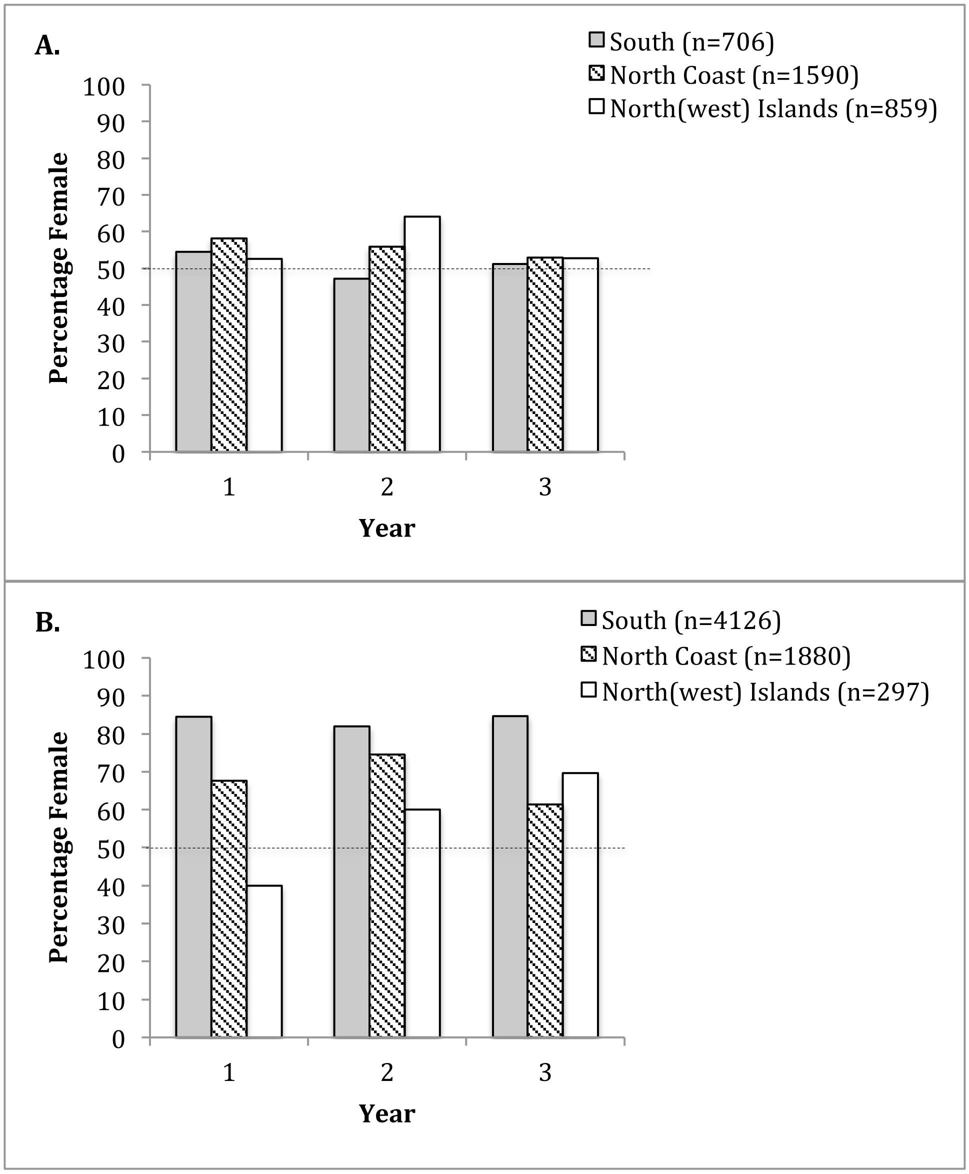


Figure 10: Mean (S.E.) number of eggs produced per trap of (A) legal and (B) sub-legal, (C) legal and sub-legal (total) lobsters in three regions, over three years, within the Southern California Bight; South, North Coast, and North(west) Islands. Bars with similar letters do not significantly differ (p-value ≥ 0.05). Numbers in parentheses are the number of traps sampled in each region for all years combined.