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ARTICLE

Utility of a Collaborative At-Sea Sampling Program (CASP) for the California Spiny Lobster Commercial Fishery: Catch Characteristics and Implications for Management

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Abstract
Fisheries management, including the development of fishery management plans (FMPs), requires the best available scientific information. To address this need, we piloted a collaborative at-sea sampling program (CASP) among California commercial lobster fishermen, scientists, and fishery managers to develop scientifically rigorous protocols and collect, analyze, and interpret essential fisheries information (EFI). Significant differences in catch characteristics among three regions (South, North Coast, and Northwest Islands) were documented. Legal CPUE was generally similar among regions, whereas sublegal CPUE was consistently highest in the South, followed by the North Coast and Northwest Islands. Evaluation of size structure revealed that legal lobsters were significantly smaller, just larger than legal size, in the South than in the other two regions, suggesting a higher exploitation rate there. Despite this, the South had significantly more prerecruits than the northern regions, a fact not considered in present fishery models. We also found a female bias in the legal sex ratios in the north regions and in the sublegal sex ratios in all regions that could affect model parameters for trap vulnerability and reproductive capacity. A discrepancy in the average weight of legal lobster for the Northwest Islands was identified which has implications for the spawning potential ratio, a reference point that elicits management action. The regional variations in catch characteristics suggest that the California lobster fishery would benefit from using more sophisticated models that incorporate area-based EFI to better inform the harvest control rules. This finding supports the recommendations of the lobster FMP scientific review panel and the interests of resource managers, with the CASP data illustrating the value of the additional EFI and a mechanism for obtaining it. The demonstrated utility of the CASP for both cross-checking and providing additional data supports its ongoing use to inform management of the lobster fishery and as a model for other fisheries.

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The California spiny lobster *Panulirus interruptus* is an ecologically important species that has supported valuable commercial and recreational fisheries since the late 1800s (Wilson 1948; Odemar et al. 1975; Barsky 2001; Neilson 2011; California Department of Fish and Wildlife [CDFW] 2016). The California spiny lobster occurs on rocky reefs predominantly from Point Conception, California, to Magdalena Bay, Baja California, Mexico, but has been found as far north as Monterey, California and as far south as Manzanillo, Mexico (Schmitt 1921; Johnson and Snook 1927; Wilson 1948). In California, the primary geographic range and fishing grounds of *P. interruptus* occur in the Southern California Bight (SCB). The SCB extends from Point Conception to San Diego, which includes the Santa Barbara Channel, a transition zone where warm equatorial waters mix with cold northern waters.

Current management of the fishery includes restrictions on access (number of permits), size, season, gear type, and fishing areas (CDFW 2016). Specifically, entry into the fishery is limited to around 200 permits to control the amount of fishing effort, with 157 active commercial fishermen out of 192 permit holders in the 2013–2014 season. The fishery is restricted to early October to mid-March to protect egg brooding females, which are present in the spring and summer. The majority of landings (80%) typically occur within the first half of the fishing season, until around mid-January (Neilson 2011). A minimum lobster size of 82.6-mm carapace length (CL; corresponding to approximately 24.8-cm TL) also allows lobsters to reproduce before being harvested. Commercial trap gear must use a specific trap mesh size (5.0 × 10.1 cm) and include a single escape port (6.0 × 29.2 cm) that allows small, sublegal lobsters (lobster under the minimum legal size) to leave the trap while still retaining legal and larger sublegal lobsters within the trap. Fishing also is prohibited in several areas, including 17 coastal and 20 island marine protected areas (MPAs).

Commercial landings have fluctuated through time, but since 2000 the landings have been relatively stable at around 300–400 metric tons (in the USA) each season. Still, concern over the status of the fishery has increased in response to increased fishing effort associated with high market prices (US$22–26/lb exvessel value). Additional regulations are being considered in response to these concerns (CDFW 2016).

In accordance with the state Marine Life Management Act (MLMA) of 1999, a fishery management plan (FMP) has been developed and currently is being implemented to ensure the future sustainability of the California spiny lobster fishery (CDFW 2016). The FMP creates a framework for fishery managers to evaluate the status of the fishery and designates a harvest control rule as a mechanism to prevent, detect, and, if needed, recover from overfishing (CDFW 2016). The harvest control rule consists of three “reference points” to gauge the health of the fishery: catch (total annual catch), CPUE (number of lobsters landed per trap), and spawning potential ratio (SPR). Spawning potential ratio 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. The harvest control rule also dictates management action (e.g., increasing the minimum legal size or limiting fishing effort) if a reference point drops below a given threshold. 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 that the fishery is properly managed. Currently, the only continuous data collected is from the commercial logbook and landing receipts. The commercial logbooks provide estimates of the total number of traps pulled, legal lobsters retained, and lobsters below the minimum legal size (sublegal) released alive within a fishing block (16.1 × 16.1 km) during each season. The CPUE reference point is determined directly from this information by taking the total number of legal lobsters landed divided by the total number of traps pulled throughout the entire fishery. 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, along with other parameters derived from limited studies, is used to calculate the SPR reference point via the lobster fishery model formerly known as the Parrish Cable Model and recently updated to the Cable–CDFW Model (CDFW 2016).

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 sublegal lobsters released, as recorded in logbooks, is often an estimate, not tallied counts. Such is likely reducing 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).

Although the Parrish Cable Model makes use of the current data that are available, it does not incorporate basic essential fisheries information throughout the range of the lobster fishery. For example, the model has used data such as growth and size at maturity that are derived primarily from spatially and temporally isolated studies at the Northern Channel Islands (northern limit of fishery) rather than bightwide data collected contemporaneously over several years. Further, information on size structure, number of prerecruits (lobster that will enter the fishery the following year), 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 to facilitate the use of more robust fishery models for managing the California lobster fishery (Field et al. 2015).

Recognizing the need for additional data for management and the subsequent requirement of the lobster FMP, we developed a pilot collaborative at-sea sampling program (CASP) for the commercial California spiny lobster fishery. Collaborative at-sea sampling programs, which have been successful in other fisheries, engage commercial fishermen to collect data on their catch at sea while conducting their day-to-day fishing activities. These data are then shared and discussed with scientists and managers to inform management of the fishery (Culver et al. 2010). The pilot CASP for the California spiny lobster fishery has enabled the collection and use of spatially explicit essential fisheries information from regions throughout the SCB (see Culver et al. 2016 for details about development, testing, and evaluation of the lobster fishery CASP). Here, we explore spatial trends of catch characteristics within the commercial lobster fishery using the CASP-collected data and how these may affect the outcome of the current fishery model. This study adds information on regional variation in the essential fishery parameters (i.e., size, sex ratios, and detailed catch rates) throughout the geographic range of the California fishery. Given the different habitats and environmental conditions occurring in the SCB, we expect these parameters may vary from area to area. Information on the spatial variation of fishery parameters can be used in stock assessment models to more accurately describe the fishery, thereby enhancing management of the resource. Based on our investigations, we provide a discussion about how our findings might inform and improve management of the California spiny lobster fishery.

STUDY AREA

Data were collected throughout the spiny lobster fishing grounds in the SCB, from south of Point Conception, Santa Barbara County, to the Mexican border, including both island and coastal mainland areas. 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 (Figure 1). Six offshore islands 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 Bank, an offshore reef.

METHODS

Sampling methods.—Data were collected in collaboration with commercial lobster trap fishermen using CASP protocols during the 2012–2013, 2013–2014, and 2014–2015 spiny lobster fishing seasons. A total of 21 commercial fishermen participated in the program, with some fishermen participating in more than 1 year (Table 1). Per the program plan, the number of participants increased each year as the sampling design and protocols were finalized and the program developed (Culver et al. 2016). Commercial fishermen were hand-selected based on their fishing experience, the suitability of their fishing operation for data collection, and fishing location, with new fishing partners identified by those already participating (Culver et al. 2016). Lobster traps used in this study followed commercial gear regulations (CDFW 2016) and were primarily 0.91 × 0.71 m, with slightly larger traps (1.02 × 0.71 m) used at the islands. Salmon (family Salmonidae) and mackerel (family Scombridae) were the most commonly used bait types, but other bait was sometimes used. The amount of time from when the traps were baited and then serviced (i.e., the “soak time”) was typically 2–4 d, but in a few cases it was as short as 1 d or longer than 4 d. Traps are required to be serviced every 4 d, weather conditions permitting (CDFW 2016).

Data were collected for the first 4 months of the season (October–January), when the majority of fishing occurs. Commercial fishermen collected information on the number of legal and sublegal lobsters per trap, CL, and sex (Culver et al. 2016). The number of legal and sublegal lobsters was tallied and recorded from every trap in year 1. These data were used to establish a scientifically robust sampling design for the CASP that enabled subsampling of the traps while still providing an accurate estimate and representation of the catch (Culver et al. 2016). The resulting CASP sampling design was used in the second and third years of the project, with counts recorded for legal and sublegal lobster from a subset of traps. Traps with no lobsters were counted and recorded as empty. Size (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 also was determined by visually examining the size of the pleopods; females have large pleopods that cover the underside of each abdominal section of the tail (Shaw 1986). The accuracy of counts, measurements, and sex determination of the subsampled legal catch of each participant was validated by scientists at the port one to two times per season, with the data found to be highly accurate (see analysis in Culver et al. 2016). The use of high precision digital calipers, tally counters in areas with high catch rates, and standardized measurements and observations that fishermen and biologists are familiar with (CL, legals or sublegals, males or females) and are easily repeatable likely contributed to the high agreement in measurements and counts between each group. The resulting data set for the 3 years included counts of 28,328 lobsters from 11,471 traps, and size and sex information for 9,458 lobsters (Table 1).

Data analysis.—We compared the CASP catch data among three regions—here termed the South, North Coast, and Northwest Islands—that differed in geographic position and oceanographic conditions (Figure 1). The South region encompassed the area between San Diego and Dana Point, including San Clemente and Catalina islands. North Coast

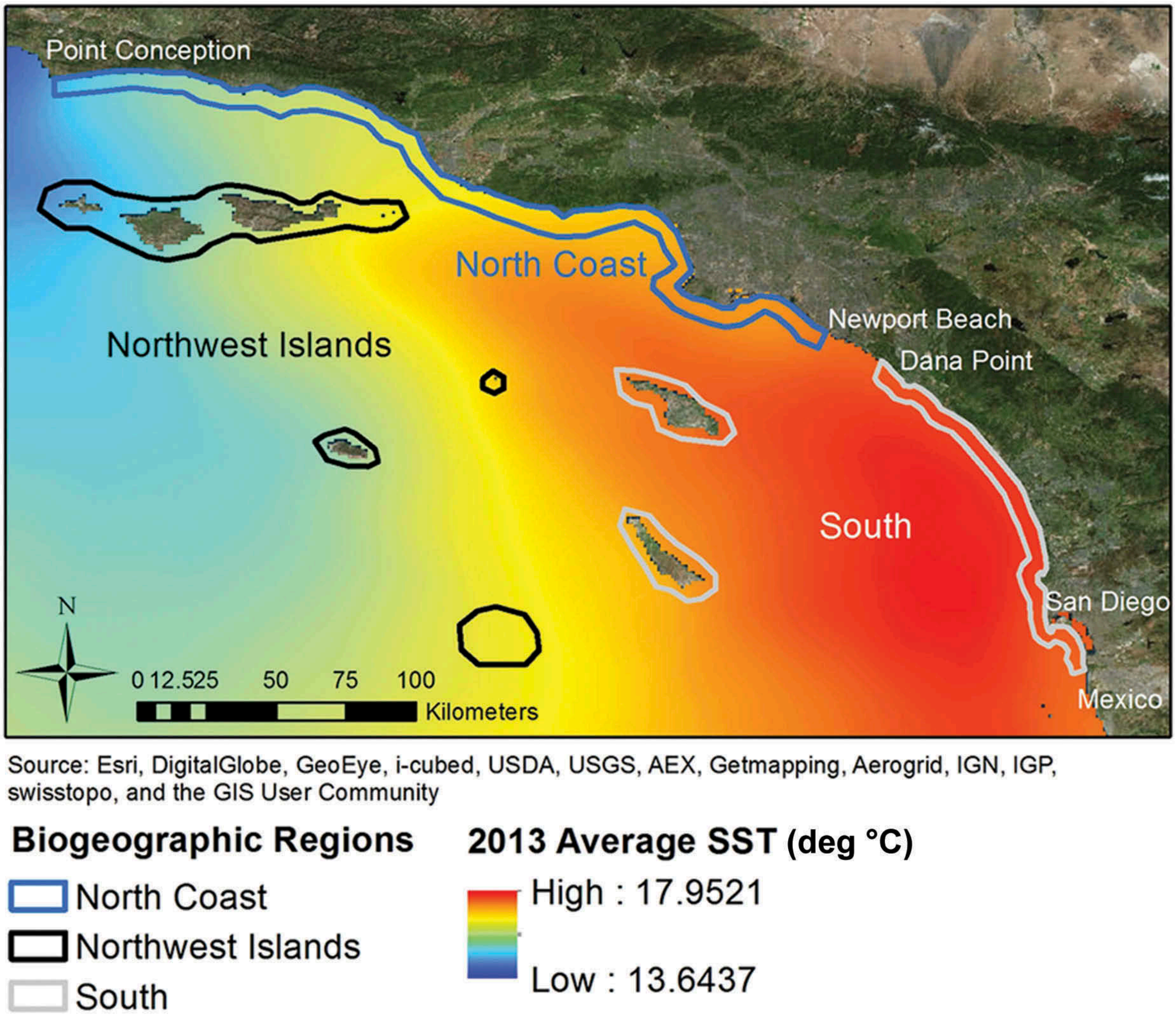

FIGURE 1. Three biogeographical regions compared in this study—South (gray), North Coast (blue), and Northwest Islands (black) overlaid with the mean 2012 sea surface temperatures (in °C).

included the mainland coastal region between Newport and Santa Barbara County. Northwest Islands included the Northern Channel Islands, Santa Barbara Island, San Nicholas Island, and Cortes Bank. While the latter two sites occur off the coast of some southern locations, circulation patterns and temperature data suggest both have environmental conditions that are influenced by cooler northerly waters (NOAA National Data Buoy Center 2012).

TABLE 1. Effort and data used in analyses and collected by the CASP for the commercial California spiny lobster fishery from October through January for three consecutive years.

Sampling effort	Year 1 2012–2013	Year 2 2013–2014	Year 3 2014–2015	Total
Commercial fishermen	8	13	14	20[a]
Trips sampled	20	69	75	164
Traps sampled	3,096	4,137	4,283	11,471
Lobsters counted	7,438	10,942	9,948	28,328
Lobsters subsampled	890	4,276	4,292	9,458

[a] Fishermen that participated in more than one season were only counted once.

We used the metrics of CPUE, size structure, number of prerecruits, and sex ratio to compare catch characteristics among the three regions. Each metric was computed for every year. The CPUE (for both legal and sublegal lobsters) was calculated by dividing the number of lobsters (legal or sublegal) by the number of traps sampled. We compared the size structure of the fished population among regions by creating relative size-frequency distributions with 6-mm CL size-classes, which is the estimated yearly growth rate of adult spiny lobster used in the CDFW stock assessment models (Neilson 2011). The estimate of the number of prerecruits—defined here as lobsters that will grow to legal size by the next fishing season—per trap was determined from the product of the number of sublegal lobster per trap and the relative frequency of the size-class 76.5–82.5-mm CL (prerecruits) in the subsample. Estimates of the number of prerecruits were expressed per trap due to variation in the number of fishermen sampling in each region. The sex ratio of legal and sublegal lobsters was calculated by dividing the number of legal or sublegal females by the total number of lobster in each of the respective categories.

We compared the reproductive capacity of the catch among regions by calculating fecundity for each region. We used data from Table 12 in Lindberg (1955) on lobster size and number of eggs to create an equation describing the relationship between CL and number of eggs for individuals ≥215-mm TL (corresponding to 71.7-mm CL, the smallest size in Lindberg's fecundity table), expressed as

$$y = 374(x) - 764{,}951\left(R^2 = 0.98\right),$$

where y is the number of eggs, and x is TL in millimeters. Since Lindberg used TL as the measurement of size, we converted CASP CL to TL using the Neilson (2011) conversion, expressed as

$$\mathrm{CL} = 1/3(\mathrm{TL}).$$

To calculate fecundity we (1) estimated the size-frequency distribution for legal and sublegal lobsters in each trap using the subsample measurement data, (2) determined the number of eggs produced for every lobster ≥215-mm TL (71.7-mm CL) using the equation derived from Lindberg's fecundity table, (3) summed the number of eggs produced for legal and sublegal lobsters in each trap, and (4) averaged the number of eggs produced per trap in each region. Estimates of fecundity were expressed per trap due to variation in the number of fishermen sampling in each region.

We also calculated the average weight of legal lobsters for each region per year by converting CL to mass using the function

$$\log(W) = \log\left(1.03992 \times 10^{-5}\right) + 2.4829 \log(\mathrm{CL}),$$

where W is the mass in kilograms, and CL is in millimeters (Neilson 2011).

To address concerns about the accuracy of the commercial logbook and landings data and the associated calculations for certain parameters of the Parrish Cable Model, we compared calculations of CPUE and average weight of legal lobsters for landings–logbook data from October through January for the 2012–2013 and 2013–2014 fishing seasons (CASP years 1 and 2) to CASP-based calculated values for the same time period. Logbook and landings data were edited prior to analysis to remove entries with missing information, such as the number of traps pulled or lobsters retained. Only logbook entries with a single identification (ID) number and matching landing receipts were included in the analysis of average legal lobster weight, as suggested by CDFW (T. Buck, CDFW, personal communication). Catch per unit effort was calculated by dividing the number of lobsters retained by the number of traps pulled per logbook ID. The average weight of legal lobsters was calculated by dividing the total weight on the landing receipts by the total number of lobsters retained. Average CPUE and legal lobster weight were calculated among seasons (n = 2) for each data set.

Statistical comparisons.—A mixed-model ANOVA with year as a random factor and region as a fixed factor was used to compare CASP data on mean size (CL), CPUE, the number of prerecruits (year-1 size-class), and fecundity among regions for each year. If there was a significant interaction between region and year, a one-way ANOVA with Tukey–Kramer post hoc tests was used to explore differences among regions within years. Only P-values for ANOVA results are presented here. Additional statistical detail is provided in Yaeger (2015). A chi-square test of independence was used to compare size-frequency distributions, and sex ratios among regions. A chi-square test also was used to test for deviations from a 1:1 sex ratio, the ratio used in fishery models for the lobster population for each region. Lastly, paired t-tests were used to test differences between the averages of legal CPUE and weight of legal lobsters derived from CASP and CDFW data (commercial logbook and landing receipts). All analyses were conducted using SAS software, version 9.4 (SAS Institute, Cary, North Carolina).

RESULTS

Catch per Unit Effort

Given the significant interaction between region and year ($F_{4,\ 11462}$ = 7.57, P < 0.001) on legal CPUE (i.e., catch per trap), comparisons were made among regions within years. There was no difference in legal CPUE among regions in year 1 or year 3, with legal CPUE values ranging from 0.4–0.6 (P > 0.05; Figure 2A). However, in year 2 the mean ± SE legal CPUE in the North Coast (0.66 ± 0.03) was significantly higher than in both the South (0.42 ± 0.02; P < 0.05) and Northwest Islands regions (0.54 ± 0.02; P < 0.05).

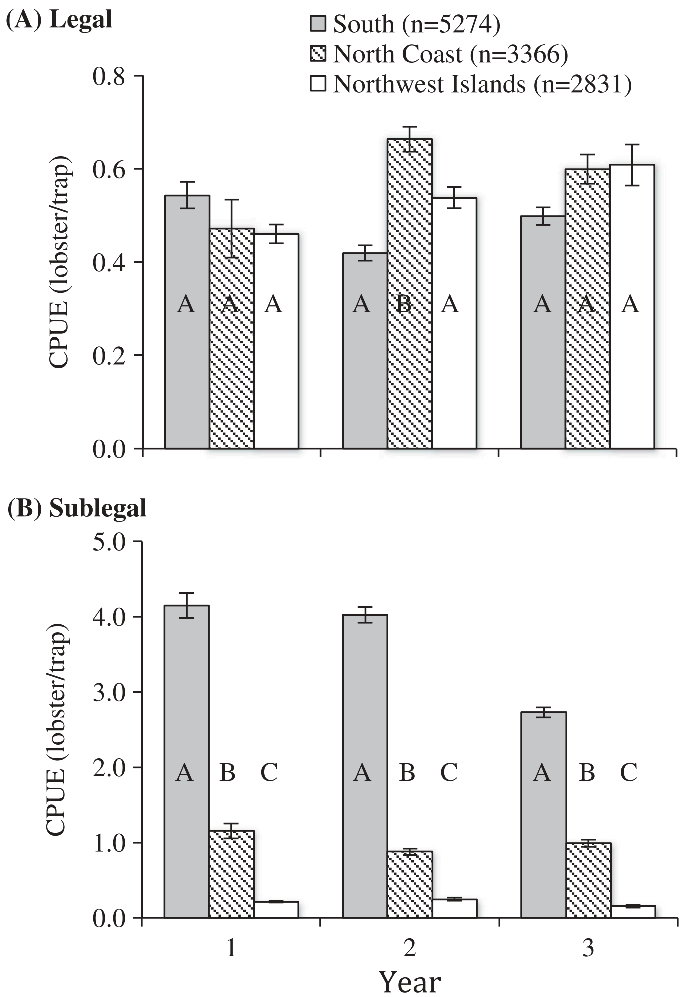

FIGURE 2. Mean number of **(A)** legal and **(B)** sublegal lobsters caught per commercial trap (CPUE) from three regions, over 3 years, within the SCB: South, North Coast, and Northwest Islands. Error bars represent ±SE. Bars with similar letters do not significantly differ ($P \geq 0.05$). Numbers in parentheses are the number of traps sampled in each region for all years combined. Scales vary.

Given the significant interaction between region and year ($F_{4,\ 11,462} = 25.61$, $P < 0.001$) for sublegal CPUE, comparisons also were made among regions within years. In all years, sublegal CPUE was significantly higher in the South, followed by the North Coast and Northwest Islands ($P < 0.05$; Figure 2B). Averaged across years, values for sublegal CPUE ± SE were 3.63 ± 0.45 in the South, 1.01 ± 0.08 in the North Coast, and 0.20 ± 0.03 in the Northwest Islands.

Size Distribution

The size distribution of trapped lobsters differed significantly ($P < 0.01$) among regions each year (Figure 3I–III). Catch in the South region consisted primarily of sublegal lobsters that would be entering the fishery the following year as recruits (i.e., 76.6–82.5-mm CL) and of legal lobsters that had just recruited into the fishery (i.e., 82.6–88.5-mm CL); large legal lobsters (>94.5-mm CL) were seldom caught in this region. In contrast, catch in the Northwest Islands region consisted primarily of large legal lobsters; lobsters >94.5 mm made up almost 30% of the catch, and few sublegal lobsters were caught there. The size distribution of trapped lobsters in the North Coast region was intermediate between the South and Northwest Islands regions.

Given the significant interaction between year and region on the mean size of legal lobsters ($F_{4,\ 3,146} = 9.35$, $P < 0.001$), comparisons were made among regions within years. Sizes in CASP year 1 in the South and North Coast regions were similar and significantly smaller than lobsters in the Northwest Islands ($P < 0.05$; Figure 4). In CASP years 2 and 3, sizes were significantly smaller in the South, largest in the Northwest Islands, and of intermediate size in the North Coast region ($P < 0.05$). Averaged across years, legal lobsters were smaller in the South (85.6 ± 0.4-mm CL, $\bar{x}$ ± SE) compared with the North Coast (89.6 ± 1.7 mm) and Northwest Islands (97.2 ± 1.3 mm).

Prerecruits

Because of a significant region by year interaction ($F_{4,\ 11,462} = 22.46$, $P < 0.001$) on the number of prerecruits per trap, comparisons were made among regions within each year. For all years, there were significantly more prerecruits per trap in the South, followed by the North Coast and Northwest Islands ($P < 0.05$; Figure 5). Averaged across years, numbers of prerecruits per trap ± SE was 2.90 ± 0.35 in the South, 0.77 ± 0.04 in the North Coast, and 0.16 ± 0.02 in the Northwest Islands.

Sex Ratios

For all years combined, the sex ratio of trapped legal lobsters varied from the expected 1:1 (male : female) assumed for the population (Lindbergh 1955). The sex ratio was significantly biased towards females for the North Coast (54.8% female, $\chi^2 = 14.53$, $P < 0.001$) and Northwest Islands (58.0% female, $\chi^2 = 21.85$, $P < 0.01$), but not for the South (50.1% female, $\chi^2 = 0.013$, $P = 0.91$; Figure 6A). This pattern was largely driven by sex ratios occurring in CASP year 2, when the sex ratio of legal lobsters was significantly biased towards females for the North Coast (56.0% female, $\chi^2 = 12.27$, $P < 0.001$) and Northwest Islands (64.1% female, $\chi^2 = 31.68$, $P < 0.01$), but not the South (47.1% female, $\chi^2 = 0.76$, $P = 0.38$). In the other two CASP years (1 and 3), legal sex ratio in all regions was not significantly different from the expected 1:1. A comparison of legal lobster sex ratios among regions also only differed for year 2 ($\chi^2 = 17.52$, $P < 0.001$).

Unlike the sex ratios for trapped legal lobsters, the sex ratio of trapped sublegal lobsters for all years combined was significantly different from 1:1 ($P < 0.01$). Overall, there was a female bias in all regions, ranging from 83.4% female in the South to 67.6% in the North Coast to 60.9% in the Northwest Islands (Figure 6B). Within years, female lobster accounted

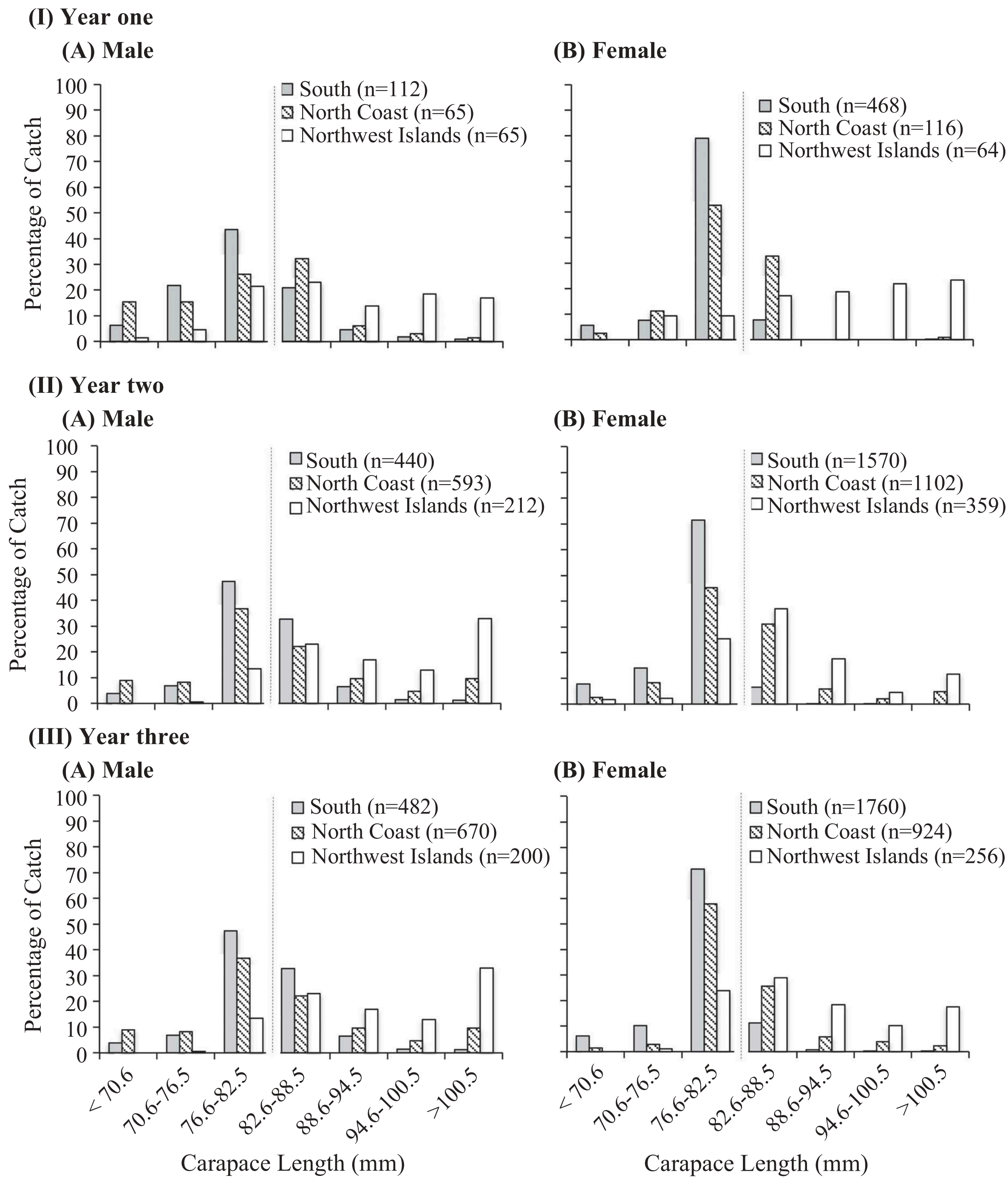

FIGURE 3. Size distribution of (**A**) male and (**B**) female lobsters caught in commercial traps within the SCB: South, North Coast, and Northwest Islands. **(I)** Year 1 of CASP (2012–2013). **(II)** Year 2 of CASP (2013–2014). **(III)** Year 3 of CASP (2014–2015). Sublegal lobsters are to the left of the dashed line, and legal lobsters are to the right. Numbers in parentheses are the number of lobsters subsampled in each region.

for over 80% and 60% of the sublegal catch for the South and North Coast, respectively, for all 3 years. Similarly, over 60% female lobster occurred for the Northwest Islands in years 2 and 3. An exception was the high proportion of male sublegal lobsters in the Northwest Islands (~60%) in CASP year 1, although the sex ratio was not significantly different from 1:1 ($\chi^2 = 1.2$, $P = 0.27$). This could be due to a low sample size ($n = 30$) and statistical power ($1 - \beta = 0.20$). A comparison of sublegal lobster sex ratios among regions indicated a significant difference for all 3 years ($P < 0.01$).

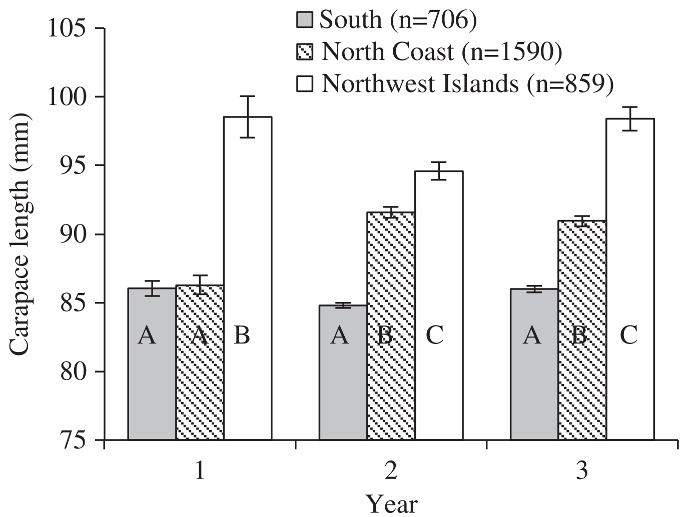

FIGURE 4. Mean CL of legal lobsters caught in commercial traps from three regions, over 3 years, within the SCB: South, North Coast, and Northwest Islands. Error bars represent ±SE. Bars with similar letters do not significantly differ ($P \geq 0.05$). Numbers in parentheses are the number of lobsters subsampled in each region for all years combined.

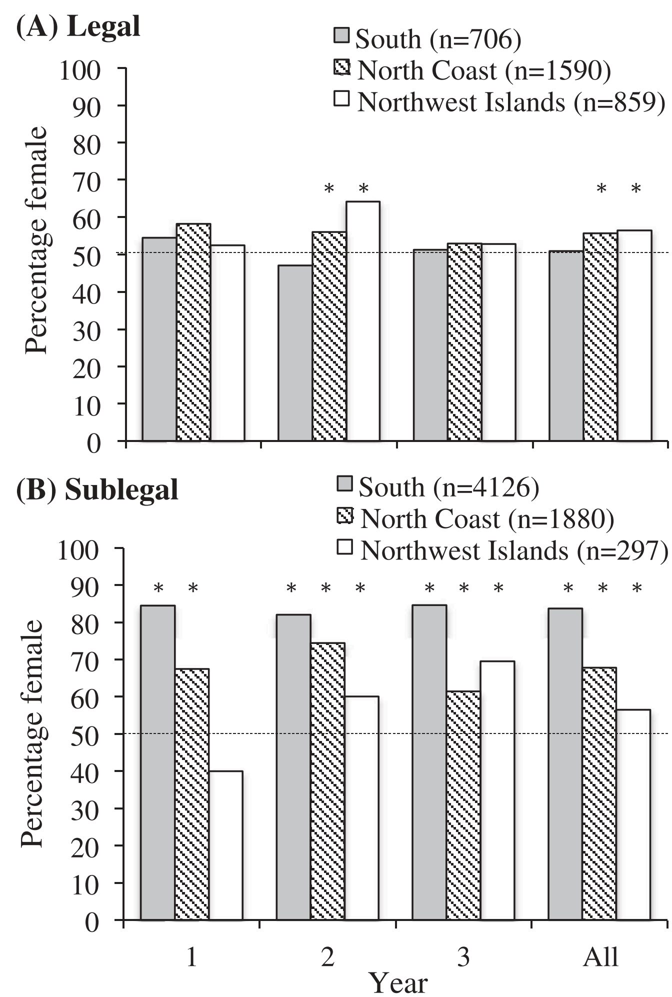

FIGURE 6. The percent of female **(A)** legal and **(B)** sublegal lobsters caught in commercial traps for three regions, over 3 years and all years combined (All), within the SCB: South, North Coast, and Northwest Islands. Numbers in parentheses are number of lobsters subsampled in each region summed over all years. The line represents the 1:1 ratio. Bars with an asterisk are significantly different than a 1:1 sex ratio ($P < 0.05$).

Fecundity

Because there was a significant year-by-region interaction for egg production ($F_{4,\ 11,462} = 10.82$, $P < 0.001$) by trapped legal lobsters, we compared values among regions for each year. Egg production of legal lobsters tended to be lowest in the South, highest in the Northwest Islands, and of intermediate value in the North Coast; however, this trend was only significant in year 3 ($P < 0.05$; Figure 7A). Averaged across years, legal egg production per trap ± SE was 49,000 ± 5,600 eggs in the South, 83,000 ± 7,200 in the North Coast, and 98,000 ± 10,000 in the Northwest Islands.

Patterns of egg production by sublegal lobsters were more striking. Again, due to a significant year-by-region interaction ($F_{4,\ 11,462} = 20.38$, $P < 0.001$) comparisons were made among regions within years. Sublegal egg production per trap was significantly higher in the South, followed by the North Coast and Northwest Islands in all years ($P < 0.05$; Figure 7B). Averaged across years, sublegal egg production per trap ± SE was 360,000 ± 43,000 eggs in the South, 83,000 ± 6,200 in the North Coast, and 14,000 ± 2,200 in the Northwest Islands.

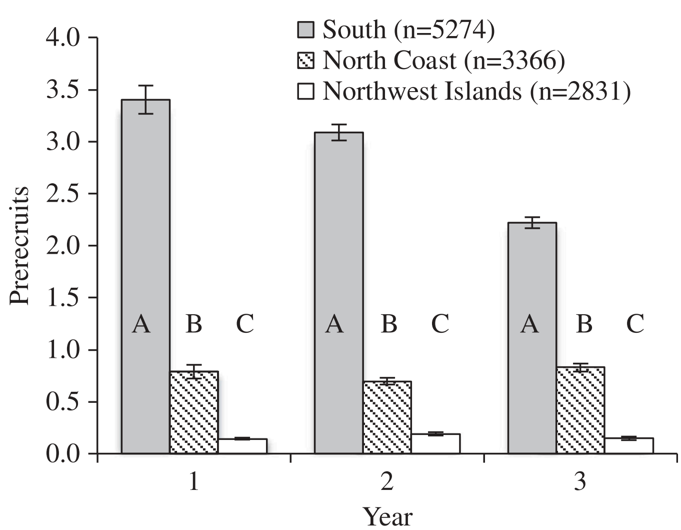

FIGURE 5. The mean number of lobster per commercial trap that will grow to legal size by the next fishing season (prerecruits) for three regions, over 3 years, within the SCB: South, North Coast, and Northwest Islands. Error bars represent ±SE. Bars with similar letters do not significantly differ ($P \geq 0.05$). Estimate based on a 6-mm growth rate and the legal size (82.6-mm CL). Numbers in parentheses are the number of traps sampled in each region summed over years.

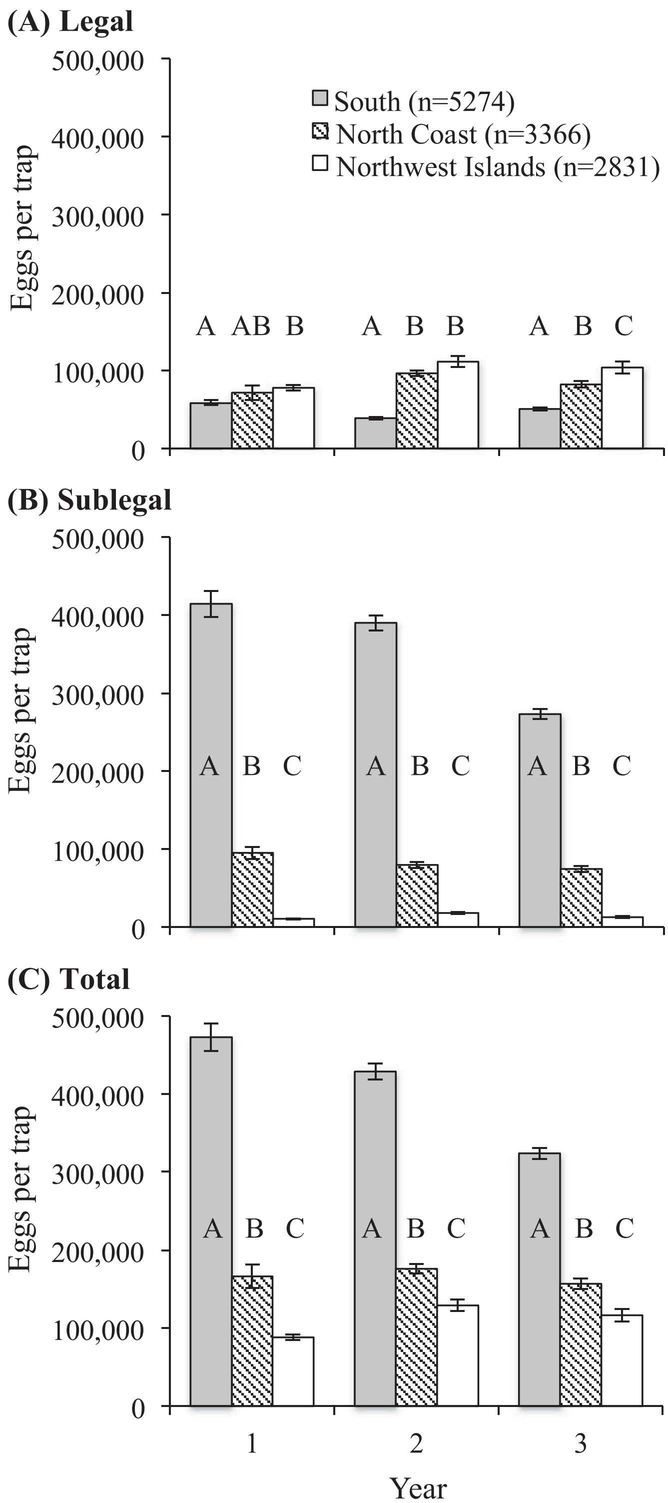

FIGURE 7. Mean number of eggs produced per commercial trap of **(A)** legal, **(B)** sublegal, and **(C)** total (legal plus sublegal combined) lobsters in three regions. Error bars represent ±SE. Means are based on size data combined over 3 years within each region (South, North Coast, and Northwest Islands). Bars with similar letters do not significantly differ ($P \geq 0.05$). Numbers in parentheses are number of traps sampled in each region summed over all years.

Patterns of total egg production (legal and sublegal lobsters combined) were similar to the patterns for sublegal egg production. Given the significant region-by-year interaction ($F_{4, 11,462} = 9.39$, $P < 0.001$), comparisons were made among regions within years. In all years, total egg production was significantly higher in the South, lower in the Northwest Islands, and of intermediate value in the North Coast region ($P < 0.05$; Figure 7C). Averaged across years, total egg production per trap ± SE was 408,000 ± 44,000 eggs in the South, 170,000 ± 5,500 in the North Coast and 110,000 ± 12,000 in the Northwest Islands.

Comparison of California Department of Fish and Wildlife and CASP Data

The mean legal CPUE ± SE for all regions combined derived from the first two years of data (Year 3 data were not yet available from CDFW) were similar between CDFW and CASP ($t = 0.42$, $P = 0.75$); 0.53 ± 0.02 legal lobsters per trap for CDFW compared to 0.52 ± 0.02 CASP data (Figure 8A). Similar results occurred when separated out by regions; CDFW and CASP estimates of mean legal CPUE were not significantly different in the North Coast ($t = 0.31$, $P = 0.81$), South ($t = 1.76$, $P = 0.33$), and Northwest Islands ($t = 0.35$, $P = 0.78$). The mean legal CPUE ± SE from CDFW data were 0.53 ± 0.02 in the North Coast, 0.56 ± 0.02 in the South, and 0.48 ± 0.03 in the Northwest Islands, compared with corresponding years of CASP legal CPUE estimates of 0.57 ± 0.1 in the North Coast, 0.48 ± 0.06 in the South, and 0.50 ± 0.04 in the Northwest Islands.

The mean weight of legal lobsters ± SE for all regions derived from the 2 years of CDFW data were again similar to the estimate from the CASP data ($t = 5.89$, $P = 0.11$); 0.78 ± 0.001 kg compared with 0.79 ± 0.001 kg, respectively (Figure 8B). However, when separated out to regions, there was a nearly significant difference between CASP- and CDFW-based calculations for mean weight of legal lobster for the Northwest Islands ($t = 11.27$, $P = 0.06$), but not for the other two regions (North Coast: $t = 0.51$, $P = 0.70$; South: $t = 0.46$, $P = 0.73$). Mean weight ± SE from CDFW data were 0.78 ± 0.02 kg in the North Coast, 0.66 ± 0.01 kg in the South, and 1.32 ± 0.01 kg in the Northwest Islands, compared with corresponding years of CASP mean weight estimates of 0.73 ± 0.06 kg in the North Coast, 0.65 ± 0.01 kg in the South, and 0.92 ± 0.05 kg in the Northwest Islands.

DISCUSSION

Regional Catch Characteristics

Catch characteristics of the lobster fishery varied among the South, North Coast, and Northwest Islands regions. Notably, although the average catch (as legal CPUE) was similar among regions, large lobsters (>89-mm CL) made up a much greater percentage of the catch in the two northern regions. Trapped legal lobster in the South region consisted

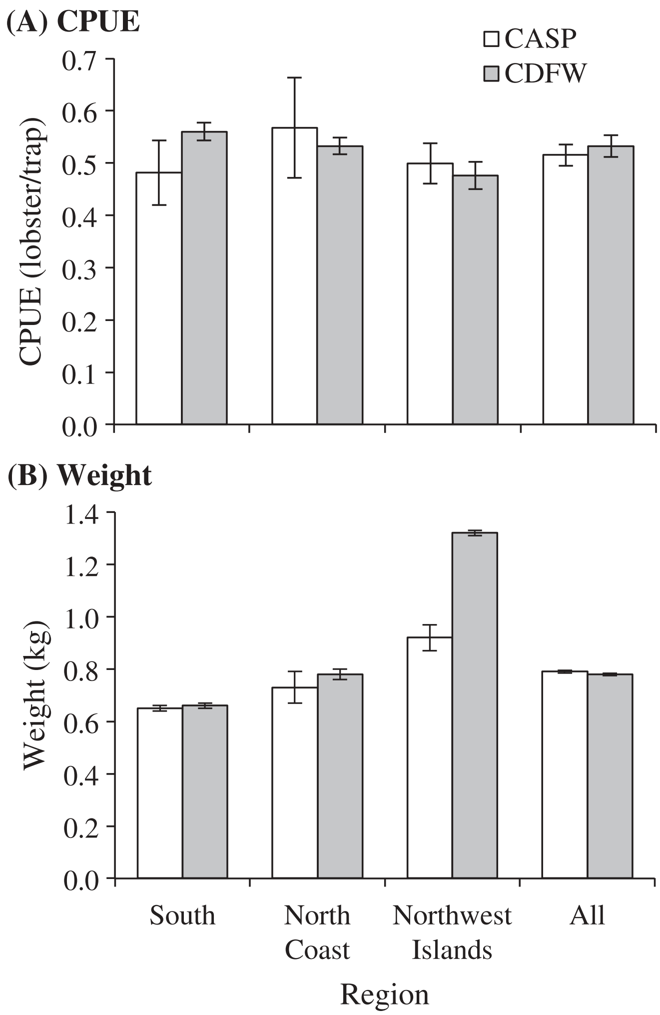

FIGURE 8. Comparison of the mean **(A)** CPUE and **(B)** legal lobster weight derived from CASP and CDFW for 2 years of corresponding commercial catch data, for three regions within the SCB (South, North Coast, and Northwest Islands) as well as all regions combined (All). Error bars represent ±SE.

primarily of individuals that were not much larger than the legal size limit. This pattern was accompanied by a much higher catch of sublegal lobsters in the South compared with the two northern regions. The lower average catch of larger legal lobsters in the South could be the result of much greater fishing pressure in that region, leading to the depletion of legal lobster each season. This hypothesis is supported by CDFW commercial logbook data (October to January 2012–2014) that show 53% of the total trap pulls occurred in this region compared with 25% in the North Coast and 22% in Northwest Islands. The commercial logbook data also show a sharp decline in legal lobster CPUE as the season progresses in the South, suggesting depletion over time, whereas this pattern is not as evident in the Northwest Islands and North Coast regions. The much higher catch of sublegal lobsters in the South, compared with the Northern regions, also suggests that the lower catch of larger legal lobsters in the South is unlikely due to recruitment limitation into the fishery. Further, while there were fewer sublegal lobsters in the catch in the northern areas, similar levels of harvest occurred over the years of the project. Given that *P. interruptus* maintains small home ranges and tend to exhibit site fidelity (Hovel and Lowe 2007; Withy-Allen and Hovel 2013; Hovel et al. 2015), it is unlikely that this pattern is the result of large-scale south-to-north migration.

Differences in recruitment rates of postlarvae (puerulus) could also explain the significant variation in CPUE levels of trapped sublegal lobsters among regions. Little is known, and there is much debate, over the recruitment dynamics of *P. interruptus*, particularly larval dispersal and retention (Lindbergh 1955; Johnson 1960; Pringle 1986; Koslow et al. 2012). These parameters are difficult to study because *P. interruptus* has 12 larval stages that develop over 5–9 months out to 350 mi offshore from the surface to a water depth of 400 ft (Barsky 2001) within complex physical oceanographic conditions of the SCB. However, the majority of studies have shown that the abundance of the pelagic lobster larval stage (phyllosoma) is higher during periods of warm water, such as occur in El Niño years, 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 such that recruitment is usually higher there. In contrast, the Northwest Islands and North Coast regions have cooler water and are at the northern limit of the core range of *P. interruptus*, suggesting that comparatively less recruitment occurs there. Future research is needed to determine larval sources and sinks of *P. interruptus* to better understand the role it may play in explaining differences in the size structure of trapped lobsters among regions.

The CASP data identified female biased sex ratios for legal lobsters in the North Coast and Northwest Islands in year 2, which could influence the model parameter pertaining to trap vulnerability that currently assumes male and females are captured at the same rate. This, in turn, could impact SPR as a reduction of reproductive capacity may occur as more female lobsters are removed from the population than males. Further, the regional variation in sex ratios suggests the trap vulnerability parameter should also vary among regions. Based on these findings and given that sex ratios are known to be highly variable throughout the year (Lindbergh 1955; Hovel and Neilson 2011; Hovel et al. 2015), continued collection of sex ratio information for the catch is critical for determining if the female-biased catch occurs frequently and varies among regions. If so, future modeling efforts should incorporate differences between sexes and among regions. Further, concurrent diver surveys and trapping studies should be conducted to verify a 1:1 sex ratio throughout all regions of the SCB and the potential influence of trapping bias, as this would affect the starting sex ratio in fishery models and the interpretation of trap vulnerability.

Our results suggest a high degree of regional variation in reproductive capacity of the fished population, with greater egg production in the South compared with either the North Coast or Northwest Islands. This is a consequence of the much higher abundance of trapped mature sublegal lobsters, which are released back into the population and continue to contribute to reproductive output, in the South compared with the North Coast and Northwest Islands regions. Importantly, 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 and Neilson 2011; Hovel et al. 2015), while the smallest SAM reported in the North Coast region (Palos Verdes) was about 63 mm (Lindbergh 1955). The variation in SAM may be due to differences in temperature, as numerous studies of other lobster, including spiny lobster, have documented an earlier onset of maturity in warmwater areas (Templeman 1936; Annala et al. 1980; Little and Watson 2005; Gardner et al. 2006). Unlike in the South, our calculations based on the CASP data suggest that egg production in the Northwest Islands is greatest in the legal fraction of the population, which is vulnerable to fishing and thus at greater risk of reduction in egg production.

Implications for Management

It is important to recognize that the data collected through the CASP do not constitute a standardized survey of the lobster population; rather, the CASP is an index of the fraction of the population available and selected by the commercial fishery. A standardized survey requires intensive sampling across regions stratified by depth and habitat. Further, the CASP does not address the recreational fishery, which also is likely impacting size structure and other aspects of the fishery. Little is known about the recreational harvest; however, recent estimates by the CDFW (CDFW 2016) suggest it contributed on average an additional 150 metric tons/year, constituting 28–38% of the total catch (commercial and recreational combined), a substantial component of the fishery that needs to be addressed.

Despite these shortcomings, the CASP data, at a minimum, provide information that can be used to supplement and cross-check calculations made using the commercial landings receipts and logbook data provided to CDFW. Overall, our CASP results for fishery-wide estimates of CPUE and lobster weight were consistent with those from the CDFW data despite a lower sample size (Neilson 2011; CDFW Commercial Fishery Landings Receipt and Logbook Data 2012–2014). This indicates that the sample sizes and area coverage used in our initial lobster fishery CASP are sufficient to provide accurate estimates of these parameters. Further, as an additional source of data, the CASP has the added benefit of providing direct measures (counts) of the legal CPUE reference point, whereas the CDFW data are estimates (often rounded numbers). Collaborative at-sea sampling program fishermen undergo rigorous training and collect data using well-defined protocols and specific equipment (digital caliper, counters) that help reduce errors and eliminate the need for estimated data, with the data validated by CASP scientists. The CASP protocols help to reduce the occurrence of missing values and erroneous entries as occurs with logbook data. Thus, while CASP data are collected from fewer sites and fishing trips than the CDFW data, at a minimum they are a valuable second source of information for the fishery that provide accurate data for determining CPUE within and among regions, with efficient measures for quality assurance and control of data that require relatively little time and effort with lower chance of errors making them.

Collaborative at-sea sampling program data can also improve the accuracy of the SPR reference points. While estimates of the average weight of the catch, a variable used in current calculations of SPR, were similar between CDFW and CASP data for the South and North Coast regions, the average weight estimates from CDFW in the Northwest Islands region was nearly 18% larger than the CASP estimate (corresponding to 114- and 97-mm CL, respectively). A trapping study conducted around the Northern Channel Islands just prior to the CASP effort documented similar results, with an average size ranging from 90- to 96-mm CL outside of the island MPAs (including fishing grounds) and about 100-mm CL inside MPAs (where fishing is restricted; Kay et al. 2012), sizes that are smaller than the average size (114-mm CL) determined from the logbook–landing data. Overestimation of the average legal weight of the catch would result in a higher SPR reference point, the only reference point that alone can trigger management actions, potentially leading to an incorrect depiction of fishery health. The identification of this overestimate of average legal size of the catch for the Northwest Islands region from CDFW data highlights the value of the CASP data in cross-checking the calculations of SPR and improving the ability to identify suitable management actions based upon the analysis of these data.

While the cross-checks provided by the lobster fishery CASP are beneficial, the greatest asset of the CASP is the additional essential fisheries information (EFI) it can provide. Per the intent of the CASP, the collected data support the need and provide the data for a more robust fishery model, such as one that is age structured. Our project team developed this project in collaboration with CDFW to provide a mechanism for collecting, analyzing, and interpreting EFI that largely did not exist over the entire range of the fishery and was needed to improve modeling of the fishery, something that has since been recommended by the lobster FMP Scientific Review Panel (Field et al. 2015). Our analyses already have illustrated the importance of fishery-wide collection of size distribution and sex ratio data given the differences among regions, and the implications of these data for fisheries models. Without these data, interpretations of the status of the fishery may be at risk of being incomplete and potentially incorrect. The long-term implementation of the CASP can enhance modeling capabilities and help move this fishery and its management from a data-poor to a data-moderate and potentially a data-rich situation.

Collectively, results from this study suggest that area-based information should be considered when determining the status of the California spiny lobster fishery. With the current method of managing the fishery, if a reference point in one region is below the threshold, but 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. Several other lobster fisheries, including the fishery for *P. interruptus* in neighboring Mexico, not only incorporate area-based information to better assess the status of the fishery, but they have also implemented area-based management (Acheson et al. 2000; Yandle 2006; Muñoz-Núñez 2009; Pérez-Ramírez et al. 2012; De Lestang et al. 2015). This type of management allows a more localized adoption of measures when needed, as some regions may benefit from added management, while other regions may be hindered by further restrictions. More complex and sophisticated models will be required for California to consider this type of management strategy, further supporting the continued collection of EFI for the lobster fishery.

The data analyses and discussions that occurred during this project also identified the critical need for gathering some basic life history information for lobster throughout the fishery's range. In particular, fecundity measurements, which are critical in estimating SPR, are based on egg production estimates that use an equation based on egg counts measured in the early 1900s on only a few lobsters from a single location (Allen 1916; Lindbergh 1955). As the harvest control rules rely heavily on estimates of the SPR, it is essential that better measurements of egg production be obtained for lobsters of all sizes throughout the SCB. Likewise, size at maturity and growth rates used in the FMP have been derived primarily from spatially and temporally isolated studies, rather than long-term, bightwide data collection. These parameters are likely to vary throughout the bight, with smaller, faster-growing lobster maturing earlier in the south. Altogether, these factors point to the need for bightwide studies of these life history parameters to enhance management of the lobster fishery in California.

CONCLUSION

To properly manage a fishery, it is important to include data that accurately characterize the catch and life history characteristics that occur throughout the fishing grounds. The data obtained from the California lobster CASP provided timely, fishery-wide, essential information needed to enhance management that is not currently collected and was called for by a recent scientific review panel (Field et al. 2015), while also providing a collaborative approach to management. The collected CASP data already have augmented the existing fisheries data by providing accurate, fine-scale spatial information on sex ratios, reproductive capacity, size structure, and number of prerecruits, some of which has never been collected concurrently throughout the range of the fishery. The CASP data has also lead to the identification of gaps in and shortcomings of the data used to derive the harvest control rules. Further, the collected CASP data have illustrated how without consideration of the region-specific variation in catch characteristics the output of the models and the resulting proposed actions may be negatively impacted. 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 while engaging stakeholders in the interpretation of the data and associated potential management outcomes. The long-term implementation of the CASP would allow managers to cross-check calculations obtained from landing receipts and logbooks and, more importantly, move to more sophisticated modeling approaches, with the ability to track the population and cohorts over time, a further recommendation of the FMP Science Review Panel (Field et al. 2015). This, in turn, should enhance management of the California spiny lobster fishery and provide a model for obtaining EFI and integrating it with management for other fisheries over the long term.

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