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Eric Miller

MBC Applied Environmental Sciences, emiller@mbcnet.net

David G. Vilas

MBC Applied Environmental Sciences, dvilas@mbcnet.net

David Pryor

California State Parks, dpryor@parks.ca.gov

Jennifer L. Rankin

MBC Applied Environmental Sciences, jrankin@mbcnet.net

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Commercial fishery effort for California spiny lobster (*Panulirus interruptus*) off Orange County, California before State Marine Reserve implementation

Eric F. Miller,^{1*} David G. Vilas,¹ Jennifer L. Rankin,¹ and David Pryor²

¹*MBC Applied Environmental Sciences, 3000 Red Hill Ave., Costa Mesa, CA 92626, phone: 714-850-4830, fax: 714-850-4840, email: emiller@mbcnet.net*

²*Orange Coast District, California State Parks, 8471 N. Coast Highway, Laguna Beach CA 92651, 949 497-1421*

Abstract.—The California spiny lobster (*Panulirus interruptus*) commercial fishing effort along the southern Orange County, California coastline was examined using fishery-independent counts of trap marker buoys and fishery-dependent information submitted to the California Department of Fish and Game in the required commercial logbooks. Buoy counts were conducted in spatially-discrete subsections of the coastline inshore of the 30-m isobath to determine the density of fishing effort at a scale finer than is afforded by the standard fishing blocks used by the Department of Fish and Game. Both the buoy densities and fisherman-reported trap pull counts recorded declining effort across the area as the season progressed. Effort was more diffuse at the beginning of the season, but increasingly focused on areas covered by giant kelp canopy, including the boundary of a previously existing, small no-take marine reserve located in the study area. General effort declined as the frequency of capturing a harvestable California spiny lobster declined. The catch per unit effort of harvestable and sublegal individuals was found to decline at highly correlated rates with no effect on the following season. Fishing regulations in portions of this study area will be increased through the implementation of a network of no-take marine reserves. Data presented herein provides a baseline to compare future fishing effort in the Laguna Beach area after two of the three most intensively fished sites are closed due to their inclusion in the Laguna Beach State Marine Reserve and adjoining State Marine Conservation Area.

Introduction

The Orange County coastline between Huntington Beach and Doheny State Beach, California is characterized by cliff-backed sandy beaches interspersed between numerous headlands, where rocky intertidal substrate extends offshore as subtidal reefs. As a result of the extensive rocky habitat, the area is targeted by the commercial California spiny lobster (lobster; *Panulirus interruptus*) trap fishery except in the no-take Heisler Park State Marine Reserve (HPSMR) located off the Laguna coast (McArdle 1997; OCMAC¹). In the Orange County area, lobster traps are typically deployed from small boats around shallow reefs and hard structure with holes and crevices where lobsters conceal themselves during the day (Mitchell et al. 1969). California Department

*Corresponding Author: emiller@mbcnet.net

¹Orange County Marine Protected Areas Committee. 2009. MPA sites and regulations. http://www.ocmarineprotection.org/mpa_sites_and_regulations.php. Accessed 17 April 2009.

of Fish and Game designated October to March each year as the commercial lobster fishing season (Barsky 2001), with most landings historically recorded during the first month of the season (Parnell et al. 2007; CDFG 2008). California commercial fishery regulations require each trap be attached individually to a buoy marked with the owner's commercial fishing license number, followed by a "P" for commercial lobster pot to make their identification easier (CDFG 2011). After the first Tuesday in October, or nearly one week after the season opens on first October Wednesday, buoys may be submerged by a timed release device called a pop-up.

Harvest effort has been routinely recorded for the commercial fishery through logbooks (CDFG 2011). The commercial logbooks record the number of traps retrieved (pulled) and the number of lobsters taken, but they do not provide fine-scale spatial information on the location of the trap set. Rather, harvest sites are designated within California Department of Fish and Game fishing blocks, which are pre-designated 10 min latitude \times 10 min longitude areas, although blocks along the coastline are often not square and therefore of smaller and varying size. At this spatial resolution, the fishing effort along gradients inside and outside a marine protected area (MPA) cannot be fully evaluated. Therefore, we attempted to evaluate the level of fishing effort along the Orange County coastline, including the area surrounding the HPSMR, which will be subsumed into future lobster no-take marine reserves; a complex including the adjoining Laguna Beach State Marine Reserve and State Marine Conservation Area². Basic information at a spatial scale finer than the California Department of Fish and Game fishing blocks will be needed to evaluate the impacts of the newly designated MPA complex. Of specific interest is the responses in the lobster aggregations that will be released from harvest pressure within the new MPA complex. We expect areas open to fishing effort would likely receive pressures proportional to their production of harvestable (>83 mm carapace length) individuals. The presence of a no-take reserve within the area during the survey may provide insights into what future effort can be expected once the new no-take marine reserves have been implemented. We attempt to address this by first describing the present baseline effort under existing spatial management regulations prior to the implementation of the MPA complex.

Materials and Methods

Fishing pressure was estimated by counting commercial lobster fishing trap buoys as a proxy for each individual trap during the 2008–2009 commercial fishing season (1 October 2008 to 18 March 2009). Counts were conducted monthly (except February 2009) from a small vessel between 3 October 2008 and 6 March 2009 by two observers under clear skies and calm seas between 0600 and 1100 h. Final counts represent the mean of the two counts. The use of pop-ups on buoys could not be quantified, but we assumed its impact on the counts would likely be most pronounced between the first survey, completed before pop-ups were allowed, and the second survey after pop-ups were allowed. In either case, these buoy counts represent a conservative estimate of fishing effort as the number of submerged buoys could not be verified.

Surveys were completed within three California Department of Fish and Game fishing blocks (737, 738, and 757; Figure 1). These fishing blocks (block) encompassed

²California Fish and Game Commission gives final approval for south coast marine protected areas. <http://www.dfg.ca.gov/news/news10/2010121501-Commission-Approves-SCMPA.html>. Accessed, July 15, 2011.

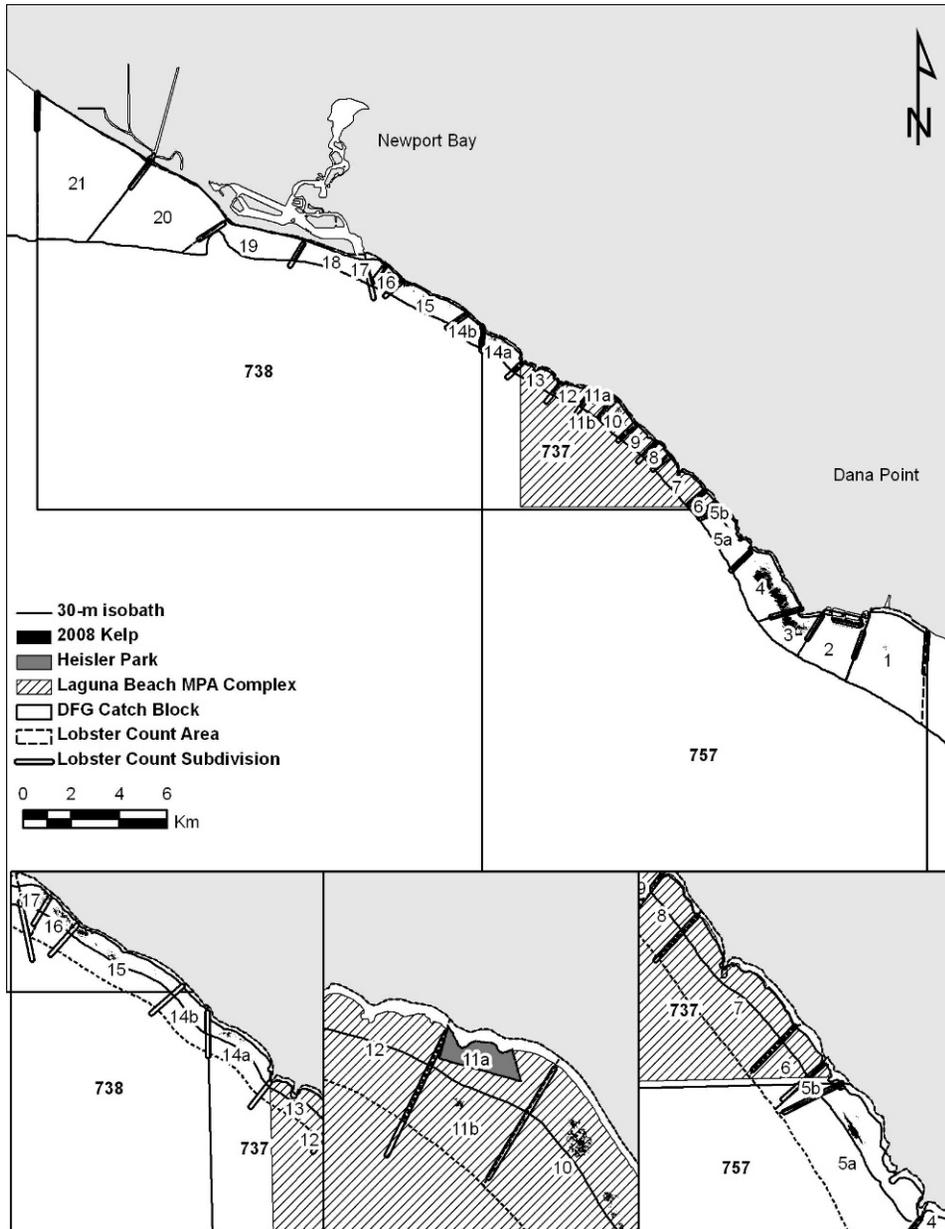


Fig. 1. Map of the study area including all three catch blocks (757, 738, and 737) and the subsections delineated for the current study, Heisler Park no-take marine reserve (11a), and the Laguna Beach MPA complex that includes the Laguna Beach State Marine Reserve and the Laguna Beach State Marine Conservation Area. The occurrence and spatial distribution of the giant kelp canopy mapped during aerial surveys in 2008 are also depicted.

approximately 62 km of linear coastline. Each block was further subdivided into subsections designated by landmarks easily recognized from the deck of the survey vessel with an offshore extent bounded by the 30-m isobath (Figure 1). The HPSMR is within block 737 designated subsection 11a. Areas (km^2) of each subsection were calculated

using ArcMAP³. The trap density (count/km²) was calculated for each subsection from the monthly counts. Similar density estimates were calculated by block to better summarize the surveys at a more comparable spatial scale to the commercial fishery records. It should be noted, however, that only a subset of the area of each block was surveyed as the blocks extended offshore beyond the 30-m isobaths. No information was collected on buoys, if present, located offshore of the 30-m isobaths. The rate of declining effort was measured as the percent of the October buoy density observed each subsequent month of the season.

Habitat information was described using giant kelp (*Macrocystis pyrifera*) maximum annual canopy area as a proxy of hard substrate within each subsection. Giant kelp canopy areas surveyed in December 2008 were compiled from MBC (2009⁴) with the subsection areas calculated in ArcMAP. Confirmation of the co-occurrence of giant kelp canopy and hard substrate was done by reviewing habitat maps in Marinemap⁵. Spearman rank correlation was used to compare the giant kelp canopy area by subsection with survey-specific buoy densities.

The CDFG provided commercial lobster fishery logbook data (2000–2009) summarized by month and fishing block on the number of traps pulled, legal individuals retained and sublegal individuals returned. Due to fishermen confidentiality requirements, data were only provided for blocks where at least three fishermen set traps that month (K. Barsky, pers. comm⁶). We examined these data for long-term trends in effort. Despite the spatial scale differences, the commercial landing data were used as an independent verification of the buoy density estimates. Linear regression was used to compare the monthly buoy count densities by block (737, 738, and 757) against the corresponding trap pull records for the 2008 commercial season. The mean catch rate (\pm standard error), or catch per unit effort (CPUE; count/trap) was calculated for the entire survey area, after combing blocks, for each of the 2000 to 2009 commercial seasons. A one-way ANOVA with SNK multiple comparison test was used to compare the October CPUEs for each commercial season for legal-sized individuals to test for changes in harvest success. Fisherman response to declining catches was evaluated by regressing the legal-sized CPUE against the number of traps pulled for each month in the 2008 season when concurrent buoy counts were completed. Linear regression was used to compare the legal and sublegal CPUEs for each block by season, 2000–2009, to examine for similarities in their trends over the season. All statistical analyses were completed using Sigmaplot 11 (SYSTAT⁷).

Results

Five monthly (minus February) counts of commercial lobster trap buoys were made during the 2008–2009 California lobster fishery season. A total of 8676 buoys were counted during the five surveys in each of the three fishing blocks. Total buoy density

³ESRI 2010. ArcMap Geographic Information System software version 10. ESRI, Redlands, California.

⁴MBC Applied Environmental Sciences. 2009. Status of the Kelp Beds 2008 San Diego and Orange Counties. Prepared for the Region Nine Kelp Consortium.

⁵Marinemap. 2011. Southcoast Marine Protected Area Habitat Mapping. <http://southcoast.marinemap.org/marinemap/>. Accessed, July 28, 2011.

⁶K. Barsky, Senior Invertebrate Specialist, California Department of Fish and Game, Ventura, California

⁷SigmaPlot version 11. Systat Software, Inc. San Jose, California.

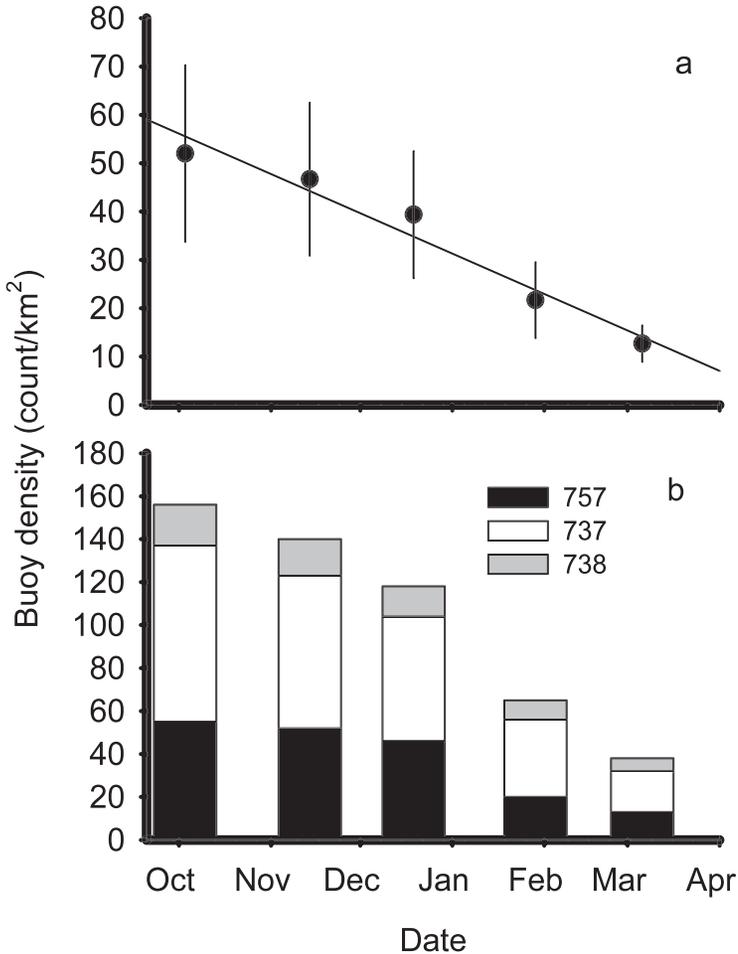


Fig. 2. a) California spiny lobster trap marker buoy density (\pm standard error) summed across all three fishing blocks by survey date during the 2008–2009 commercial fishing season and the best fit linear regression ($R^2 = 0.94$) describing the general trend, b) total buoy density in each fishing block depicted in Figure 1 by survey date.

linearly ($R^2 = 0.94$, $p = 0.006$) declined each month of the season (Figure 2a). Effort was greatest in block 737 where 51% of the total buoy density was observed, after standardizing for the area surveyed. This was followed by block 757 with 36% and block 738 with 13%. Effort in block 757 was initially the most consistent registering the smallest change between the first and second survey while the remaining block-specific densities declined each month (Figure 2b). Block 757 densities registered the largest month-month decline with 48% fewer buoys observed between the December and January surveys, as compared to the October baseline.

The subsection densities revealed distinct variations in effort within each block (Figure 3). Subsections 3, 9, and 11b were among the most intensively fished subsections. These include relatively unique areas, in comparison to the rest of the survey area, including the headlands of Dana Point (subsection 3) and an area located adjacent to the HPSMR (subsection 11b). Effort in subsections 3 and 14b was the greatest during the first survey near the season opening while subsection 11b surrounding the HPSMR

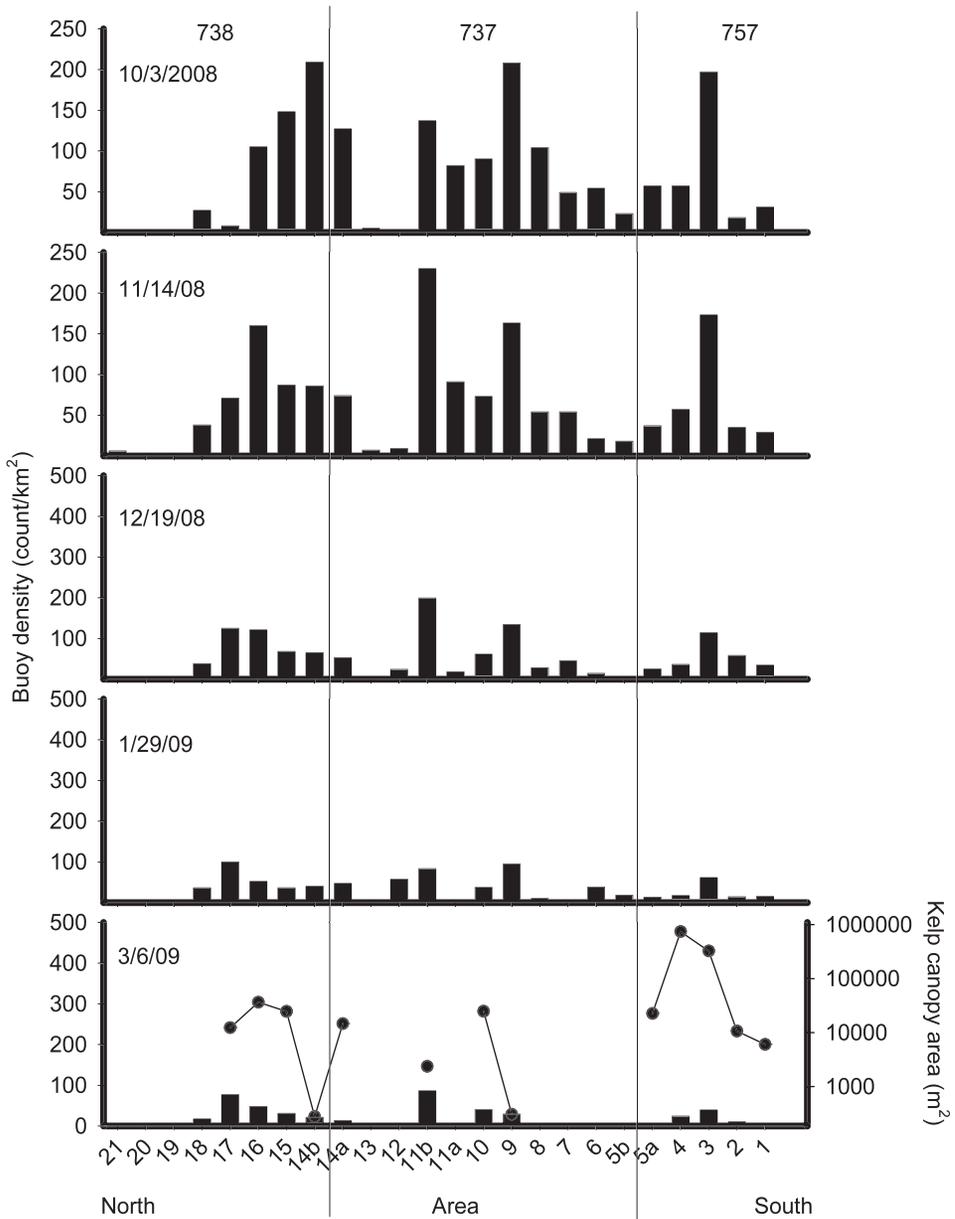


Fig. 3. California spiny lobster trap marker buoy density in each subsection of the three fishing blocks depicted in Figure 1 by survey date during the 2008–2009 commercial fishing season. The Heisler Park no-take marine reserve is subsection 11a. Maximum annual giant kelp canopy (m^2) observed during 2008 in each subsection is represented. Note the log scale for kelp canopy.

received the greatest effort during the next two surveys. Subsections 3, 9, and 11b remained the most productive throughout the season but each declined as the season progressed. Some buoys were recorded within the no-take reserve. Whether these represented traps set within the boundaries or simply a case of the buoy drifting into the reserve while the trap was set outside of the boundary could not be verified.

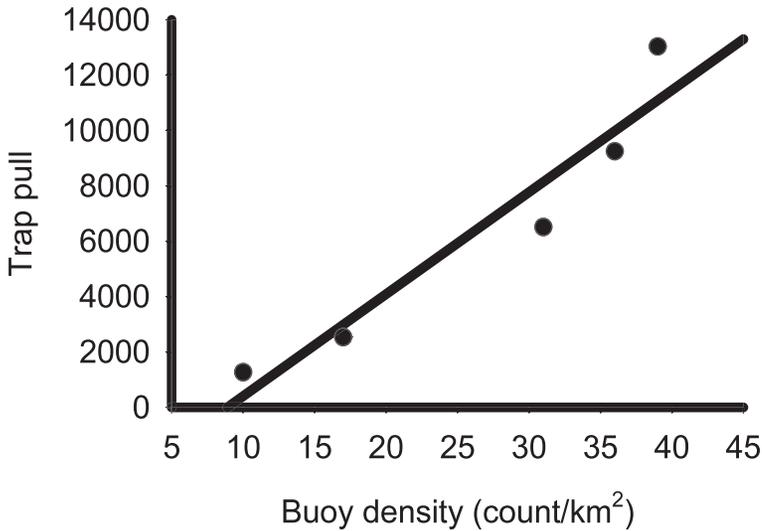


Fig. 4. Scatterplot of the number of commercial California spiny lobster traps pulled, as reported via the California Department of Fish and Game-required commercial fishing logbook, versus the buoy density (count/km²) summed across the three fishing blocks depicted in Figure 1 and monitored during the 2008–2009 commercial fishing season. The best-fit regression is drawn ($R^2 = 0.93$).

Thirteen of the 24 subsections contained reef habitat as suggested by the presence of a giant kelp canopy (Figure 1). All five subsections in block 757 were within the boundary of the Dana Point-Salt Creek kelp forest as represented by the presence of a canopy. The overall maximum canopy area was in subsection 4 with 0.743 km², although this area lies outside of the soon-to-be implemented MPA complex which will primarily encompass block 737. Subsection 3, however, had the greatest proportion of its area covered by giant kelp canopy (Figure 3). The HPSMR (subsection 11a) had no kelp canopy while the adjacent offshore and southeast area (subsection 11b) had a small area of kelp canopy (Figures 1 and 3). No surface canopy was observed to the northwest of the HPSMR within block 737 until the North Laguna kelp bed which covers subsections 14a (block 737) through subsection 17 in block 738. Spearman rank correlation analysis found a significant correlation ($p < 0.05$, $n = 24$) between each survey-specific buoy density by subsection and the associated kelp canopy. With the exception of the January 2009 survey, correlation coefficients (r) steadily increased from 0.53 for the October 2008 survey through 0.72 for the March 2009 survey.

A significant relationship ($R^2 = 0.92$, $F = 32.349$, $df = 1,3$, $p = 0.011$) was detected between the number of traps pulled reported by commercial fisherman and the buoy densities in all three surveyed blocks, combined, during the 2008 season (Figure 4). The degree of agreement between the two effort measures ranged from block 737 ($R^2 = 0.97$, $p = 0.002$) to block 738 ($R^2 = 0.86$, $p = 0.025$). Total effort was highest in block 757 in during the 2008 fishing season (Figure 2a), which likely related to the differences in size between the three blocks (Figure 1). Effort significantly responded to the legal-sized CPUE with the greatest effort occurring when legal-sized individuals were commonly taken, but declined linearly when the legal-sized CPUE declined (Figure 5; $R^2 = 0.23$, $F = 9.995$, $df = 1,34$, $p = 0.003$).

The fishery-dependent data was not standardized to area. Logbook records for the Laguna Beach area indicated CPUE for both legal-sized and sublegal-sized individuals

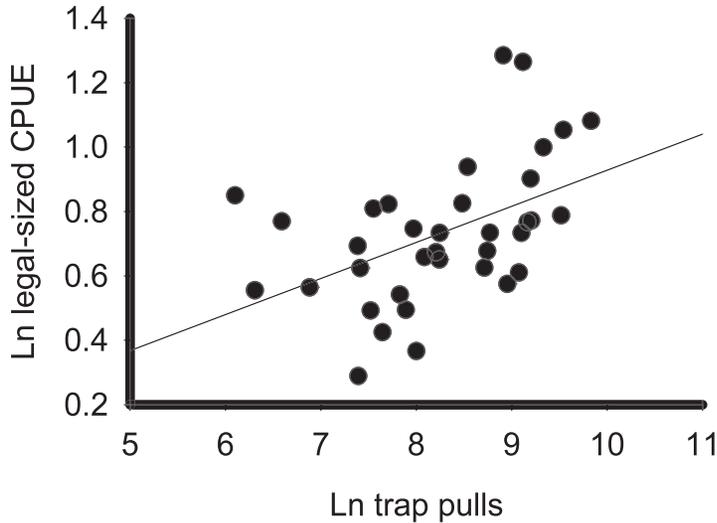


Fig. 5. Scatterplot of the number of commercial California spiny lobster traps pulled, as reported via the California Department of Fish and Game-required commercial fishing logbook, versus the legal-sized catch per unit effort (CPUE; count/trap) for the three fishing blocks depicted in Figure 1 for the 2007–2008 and 2008–2009 commercial fishing seasons, after Ln-transformation. The best-fit regression is drawn ($R^2 = 0.23$).

declined each year as the season progressed (Figure 6); often in similar significantly correlation fashion ($R^2 = 0.65$, $p < 0.001$; Figure 7). The effect of this simultaneous decline on the subsequent season was examined. Each season began with similar CPUEs for legal-sized (~ 0.7 individuals/trap) lobsters, with the exception of 2004. The October 2004 CPUE was significantly higher (ANOVA, $F = 9.731$, $df = 9,20$, $p < 0.001$) than the remaining years, but no differences were detected between any other combination of years.

Discussion

Despite the potential use of pop-up devices to minimize buoy visibility, the significant relationship between buoy densities and the number of traps pulled reported by the commercial fleet (Figure 4) validate the use of buoy counts as a fishery-independent monitoring technique. Using the combination of this and fishery-dependent logbook information, the Orange County lobster fishery was reviewed to determine the spatial distribution of effort. Although catch has been reported and fishing practice is known anecdotally, the density and location of traps set at any time during the season off Orange County, California has not been well documented. Observations of commercial lobster fishing in Orange County suggested that fishing effort was most intense at the beginning of the season, with effort declining as the season progressed. Because of minimum size requirements for the legal take of lobster, harvestable individuals should be most abundant early in the season as a result of growth during the seasonal closure. Observed fishing effort (Figure 2a) and commercial logbook information (Figure 6) concur with this hypothesis. All available measures of effort suggest that as the catch declines, fishing effort correspondingly declines (Figure 5).

More important than the sheer number of traps is their distribution throughout the area. Adult California spiny lobsters prefer high-relief rocky habitat (Barsky 2001). While

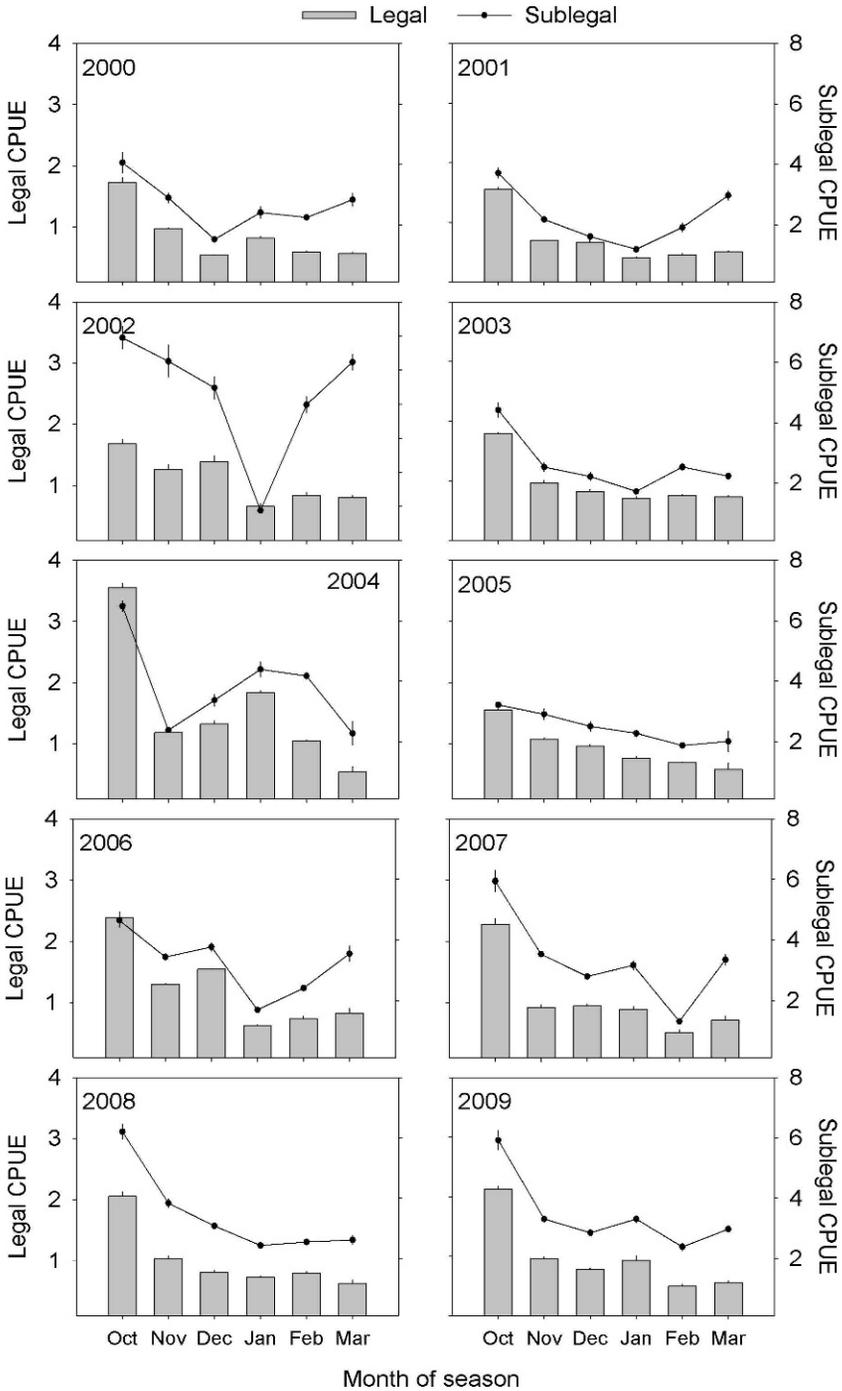


Fig. 6. The legal-sized and sublegal-size California spiny lobster catch per unit effort (CPUE; count/trap) as reported via the California Department of Fish and Game-required commercial fishing logbook during each of the 2000–2009 commercial fishing seasons.

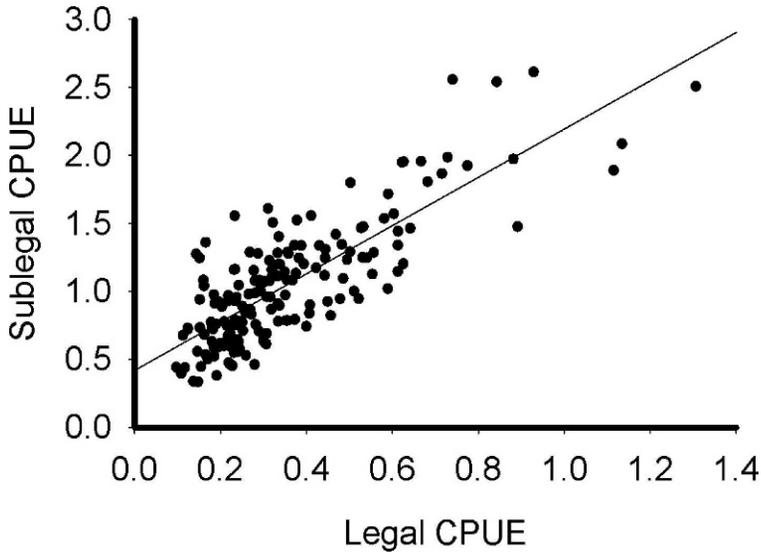


Fig. 7. Scatterplot and linear regression comparing the sublegal and legal lobster CPUEs recorded in fishing blocks 737, 738, and 757 off the Laguna Beach area, 2000–2009. The best-fit regression is drawn ($R^2 = 0.65$).

no subtidal habitat assessments were conducted during this study, the spatial distribution of giant kelp canopy can act as a proxy for hard substrate given giant kelp's general ecological need for hard substrate to anchor its holdfast (Dayton 1985). Furthermore, the significant correlations observed during each survey between the spatial distribution of buoys and kelp canopy in light of the aforementioned substrate preferences of both giant kelp and lobster was consistent with Parnell et al. (2007) who found lobsters, and fishing effort, more commonly on rocky reefs offshore of La Jolla, California.

As noted previously, the commercial fleet in the area reduced effort when the CPUE declined and therefore likely focused remaining effort on the most productive areas which were often associated with above average kelp canopies. These patterns were evident in the subsection buoy densities (Figure 2) and the significant correlations between these densities and kelp canopy area. This is consistent with Parnell et al. (2007) and Parnell et al. (2010) who found the most heavily fished areas were likely highly productive and areas of preferred habitat. As the season progressed, with the exception of January 2009, fishermen progressively abandoned the areas devoid of kelp canopy and increasingly focused their efforts to areas covered to a varying extent by kelp canopy likely due to the presence of submerged hard habitat. The comparatively elevated effort recorded near the southeastern edge of the HPSMR, especially after the first month, suggests that once the abundance of legal-sized individuals was greatly diminished in the areas available to harvest effort, fishermen targeted the edge of the HPSMR where suitable habitat was present as effort in subsection 11b consistently exceeded that in subsection 12 which adjoins the northwest border of the HPSMR. Given lobsters execute nocturnal migrations of up to 1500 m (Hovel and Lowe 2007), it is likely that these migrations potentially exposed them to fishery resources deployed near the reserve boundary similar to that reported by Goñi et al. (2006). This is consistent with fishing effort patterns in similar studies of lobster commercial effort near no-take reserves in southern California, specifically focused effort at reserve boundaries (Parnell et al. 2007; Parnell et al. 2010).

This documented commercial effort in relation to existing no-take marine reserves will likely become more relevant as new MPAs, some of which are no-take reserves, are implemented in southern California³. The pending MPA complex in our study area will encompass two of the three most productive sites currently exploited by the commercial fishery, specifically subsections 9 and 11b. This new MPA complex will likely be of sufficient size to allow some individual lobster movement within its borders without being exposed to fishing at the boundary. It will not, however, include the areas of greatest kelp canopy coverage, which will remain open to fishing. Based on the observations near the HPSMR and near the La Jolla Ecological Reserve (Parnell et al. 2007), we anticipate a significant effort along the MPA complex edge. If legal-sized lobster from within the MPA complex are exported out of the no-take area (via migration, density-dependent factors, etc.) as has been described for other spiny lobster species receiving MPA protection (Goñi et al. 2006), then these adjacent areas may become the most productive assuming suitable habitat is present.

Over the 10 commercial seasons studied, the lobster fishery along the southern Orange County coastline began with generally steady catches, excluding 2004, but quickly declined with time likely due to a lack of harvestable individuals as time passed. Surprisingly, sublegal-sized individuals declined at a rate similar to that of the harvestable stock in the Laguna area (Figures 6 and 7). Reasons for this decline are outside the scope of this study, and warrant further examination, but did not appreciably impact the next season's fishery as no significant differences were detected between the October CPUEs in 9 out of 10 seasons. These simultaneous declines and apparent non-impact on the following season superficially resembles what would be expected given the documented behavior of other spiny lobster species (*Panulirus*, *Jasus*). Specifically, a potential explanation includes a mass migration wherein all lobster size classes were observed to move from shallow spawning habitat into deeper waters (Kanciruk and Herrnkind 1978 and references therein; MacDiarmid 1991). Data reported by Parnell et al. (2007) was consistent with this as they documented a shift in effort to deeper waters during the middle of the season off La Jolla, although the total number of traps set was greatly reduced. This spatial shift in effort, small as it was, may be a fishermen adaptation to the offshore migration and consistent with that described by Kanciruk and Herrnkind (1978). Work by Hovel and Lowe (2007) confirmed movement by individual animals, but further research on the seasonal movements is needed to verify the potential similarities between the California spiny lobster and those from the Atlantic and Southern Pacific. Interestingly, Kanciruk and Herrnkind (1978) also reported that the migrating lobsters were typically smaller in size and more frequently sexually-inactive in comparison to those found at shallower depths prior to the migration beginning. Overall, these data suggest that the commercial California spiny lobster fishery in the vicinity of Laguna Beach, California is likely sustainable at this time under the present level of effort.

Acknowledgements

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