Title

Sea Urchin Gonad Index a Key to Understanding Secondary Production in the Restoration of Giant Kelp Forests off Palos Verdes

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Sea Urchin Gonad Index a Key to Understanding Secondary Production in the Restoration of Giant Kelp Forests off Palos Verdes
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Project Hypothesis
Red and purple sea urchins (*Strongylocentrotus franciscanus* and *S. purpuratus*) that live in persistent barrens are perennially starved and will have lower gonad indices (the proportion of the weight of the whole urchin that is comprised of the weight of its gonad) than their counterparts living in persistent kelp forests. Establishing sea urchin gonad indices can be use as a measure of fishery-related secondary production in nearshore rocky reef ecosystems because gonad condition is linked to the quality of the urchin's diet and correlated with environmental conditions on a fine spatial scale.

Project Goals and Objectives
The data collected during this project will be used to calculate differences in one measure of secondary production between two distinct habitat types present on the rocky subtidal of Palos Verdes e.g., sea urchin barrens and kelp forests. In the future, these sea urchin gonad indices of red and purple sea urchins in barrens and kelp forests will be applied to assess a level of secondary production resulting from large scale restoration of kelp forest on the Palos Verdes Shelf.

In addition, the project will further the developing partnership between the Santa Monica Bay Restoration Foundation (SMBRF), Santa Monica Baykeeper, Vantuna Research Group, and Center for Santa Monica Bay Studies at Loyola Marymount University. It will also give students participating in the Center for Santa Monica Bay Studies internship and volunteer program an opportunity to participate in applied marine ecology research.

Briefly describe project methodology
Three known barren sites (Christmas Tree Cove, Honeymoon Cove, and Marguerite) and three kelp forest sites (Rocky Point 1, 2, and 3) of similar depth (< 10m) off the Palos Verdes Peninsula were selected based on their exposure to similar environmental conditions and how representative they were of the particular habitat type. All sites had been previously mapped and surveyed using standard CRANE protocols (Tenera 2006). Sampling was conducted four times, on April 1, April 22, May 12, and May 26 of 2011. Urchins were collected in the morning, transported to the lab chilled with ice in coolers, and lab work took place that afternoon.

At each site, 30 S. franciscanus and 30 S. purpuratus were collected during each sampling event. Divers collected the first 30 urchins they encountered that could be removed without damage along a 30-m transect tape laid along a 5-m depth contour. Effort was made to collect urchins systematically to reduce collection bias. Care was taken to remain more than 15-m from the interface between the urchin barren and kelp forest. To measure day-of urchin densities, divers initially collected urchins from within a 2-m wide swath along the transect and noted the meter-mark at which the 30th individual was collected. However, to make the data comparable to other CRANE data, this method was changed for subsequent sampling events so that divers collected urchins parallel to, but 2-m away from the transect, while one diver

counted urchins within the 2-m swath surrounding the transect according to CRANE protocols (Tenera 2006).

Urchins were processed in the lab, grouped by the site and species (i.e., all red urchins from Site-A were processed together). The start and end times were recorded for each group. A team of several dissectors assisted a data recorder to reduce the processing time. The test diameter of each individual was measured to the nearest millimeter using calipers. Whole weight was measured to the nearest hundredth of a gram after shaking off excess water (Vadas 1997). Then urchins were dissected, their gonads removed, cleaned and weighed. Any unusual or notable appearance or circumstance was noted, such as unusual roe color or spawning.

Additionally, benthic habitat data collected as part of ongoing comprehensive monitoring were included in the analysis for this project. Differences in benthic habitat were quantified at 3 sites within the Rocky Point kelp forest and at each of the urchin barrens. Density of macroalgae were quantified along two 30-m x 2-m transects at each site. Specific minimum size criteria were applied when counting macroalgal species (e.g., Macrocystis pyrifera taller than 1 m; Eisenia arborea taller than 30 cm). Also, at each meter along each transect, a uniform point contact method was used to quantify the percent cover of bare rock and crustose coralline algae. High cover of bare rock and crustose coralline algae has been previously documented as a characteristic of urchin barrens (Harrold and Reed 1985b).

For each species of urchin, mean test diameter was compared between habitat type (barren or kelp forest) using a one-way ANOVA. Density of macroalgae per 100 m2 and percent cover of bare rock and crustose coralline algae were compared between habitat types (either barren or kelp forest) using a one-way ANOVA. Data were log10(x+1) transformed to meet model assumptions.

The relationship between urchin test diameter and gonad weight was modeled using an allometry model with an adjustment for the size when gonads begin to develop following Ebert et al. (2011): $G = \alpha (R - L)\beta$ where G is gonad weight (g), L is urchin test diameter (mm), R is the minimum size when gonads begin to develop and α and β are 2 fitting parameters which have no direct biological meaning. For *S. franciscanus*, R was fixed to a diameter of 40 mm (Kato and Schroeter 1985), and for S. purpuratus, R was fixed to 16 mm (Kenner and Lares 1991). These sizes represent the minimum size each urchin species has been observed producing viable gametes in the SCB, which are generally smaller than that of urchins collected in more northern areas of the Pacific coast (Kato and Schroeter 1985; Kenner and Lares 1991). For both species these sizes were also are in accordance with what was observed in our data, i.e. urchins collected below these sizes did not have functional gonads. Urchins below these sizes were excluded from this analysis. This function was fitted by maximum likelihood, assuming that: (1) G is normally distributed with mean given by Eq. 1; and (2) standard deviation σ) increases as a function of length: ($\sigma = cL$), where σ is the standard deviation of mean gonad weight, L is urchin diameter (mm) and c is a constant (Claisse et al. 2009). Examination of model residuals confirmed that these assumptions were appropriate.

Biological hypotheses related to ecological influences on the relationship between gonad weight and urchin test diameter using the previously described model were investigated via model selection (Burnham and Anderson 2002) using the second-order bias corrected Akaike's Information Criterion (AICc) and coded in R (R_Development_Core_Team 2010). AICc includes an additional term to correct for bias related to small sample size (n) that becomes negligible when n is large (Akaike 1973; Anderson 2008). Akaike weights (wi) were calculated to assess the relative likelihood of each model in a set and were interpreted as a weight of evidence in favor of the hypothesis represented by the model (Burnham and Anderson 2002). For each species, three models were include in a model set: (Habitat) habitat type (urchin barren and kelp forest) affects this relationship [unique parameters (α, β, c) are estimated for each habitat type]; (Habitat*Date) habitat type and collection date affect this relationship [unique parameters (α, β, c) are estimated for each habitat on each collection date]; (Null Model) no influence of habitat nor collection date on the relationship [identical parameters (α, β, c) are estimated for both habitat types across all collection dates].

To directly compare differences in gonad weight at length (diameter) among different categories (Habitat or Habitat*Date), bootstrapping was used to estimate 95% confidence intervals (Haddon 2001) around the mean gonad size predicted by the models at 84 mm for *S. franciscanus* and 45 mm for *S. purpuratus*. The overlap of the urchin test diameter size structures collected in each habitat was greatest around these sizes, and 84 mm also has important applied value for *S. franciscanus* since it is the commercial minimum size limit. Bootstrapping involved random re-sampling with replacement from the original data set to generate an equivalent data set, re-estimating model parameters from the new

data set and substituting the new parameter estimates back into Equation 1 to estimate mean gonad weight at the given urchin test diameter. This was repeated 1000 times and then the gonad weight estimates at 2.5% and 97.5% of these new distributions were taken as the lower and upper 95% confidence intervals.

Describe progress and accomplishments toward meeting goals and objectives.
All the project goals and objectives have been met. The data collected shows significant differences between barren and kelp habitats in purple urchin density, benthic algae densities and percent cover, urchin size for both species, and gonad weight at length for both species. Urchins collected from kelp sites were significantly larger and had higher gonad weight at length than those collected from barren sites. Gonad weight at length increased substantially in the urchins collected from kelp sites over the course of the study period due to pre-spawning gonad growth, while gonad weight at length remained low and relatively constant over the study period in the urchins collected from barren sites. All of this information will be used as a baseline for monitoring of future kelp restoration at the barren sites. The substantial pre-spawing gonad growth in urchins collected from kelp sites and the lack of this growth in urchins collected from barren sites demonstrates the difference in secondary production between barrens and kelp forests and demonstrates the potential value of kelp forest restoration to commercial fisheries. The significantly higher frequency of legal sized red urchins found in kelp forests than in barrens also speaks to the value of kelp forest restoration for fisheries. In addition, 33 volunteers and interns were able to assist with processing the urchins and 2 undergraduate students were able to complete independent-study credits required for their degrees through the Center for Santa Monica Bay Studies program. The project created much excitement among these volunteers because to date it has been the only marine biology project they could participate in that didn't require advanced SCUBA certifications.

PROJECT MODIFICATIONS:
The original proposal called for 50 urchins of each species to be sampled 4 times from 8 sites over the course of 3 months (February, March, and April 2011). However, processing each urchin can take up to 5 minutes. Two sites were removed from the study because they were exposed to different environmental conditions than the other sites, which might introduce extraneous factors into the analysis. The sampling period was reduced from 3 months to 2 months for the same reason. In order to reduce the potential for stress-induced spawning, it became vitally important to reduce the total number of urchins processed during each sampling event. A power analysis of the data from the first sampling event confirmed that 30 individuals per species per site and 6 sites was more than sufficient given the variability across our sites. Ocean conditions made collection impossible at one of the kelp forest sites on one of the sampling days, so only 5 sites were sampled during that sampling event. Ocean conditions also made any collection impossible in February and March. Sampling began in April and was extended into May to ensure 4 sampling events. This temporal shift also prevented us from presenting these results at Southern California Academy of Sciences, as expected. The original proposal had anticipated some of the statistical analysis would be conducted by Dr. Morris of LMU. However, his other commitments prevented his involvement in this project. Instead, all analysis was conducted by project personnel from Vantuna Research Group.

PROJECT OUTCOMES:
The results of this study have shed further insight into the ecological differences between kelp forests and urchin barrens using a metric that is relevant for commercial fisheries. These results can now be used as a baseline for measuring change in response to planned restoration. Furthermore, the results of this project show that red sea urchins inhabiting kelp forests have much higher value to the commercial red sea urchin fishery than red sea urchins inhabiting barrens. In the future, steps will be taken to use these results to define a net value increase in direct fishery benefits resulting from kelp restoration. In addition, this project generated excitement among Center for Santa Monica Bay Studies interns and volunteers for other lab-based marine-related projects and has strengthened the Center for Santa Monica Bay Studies, a partnership between SMBRF and LMU to further science and education relating to Santa Monica Bay.

IMPACTS OF PROJECT:
This project's approach of looking for fishery relevant metrics sparked discussions about incentives for restoration and resource management at the annual meeting of the Ecosystem Based Management Network. These results are of interest to the Port of Los Angeles, which is concerned with the ongoing well-being of their commercial fishermen.

BENEFITS, COMMERCIALIZATION, AND APPLICATION OF PROJECT RESULTS
The methods developed during this project will be replicated at completed kelp restoration sites in Malibu and incorporated into long-term subtidal rocky reef monitoring programs in Santa Monica Bay and elsewhere in the Southern California Bight. The results will also be used to build interest among commercial urchin fishermen in assisting with future kelp forest restoration.

ECONOMIC BENEFITS generated by discovery
Not Applicable (NA). Direct Economic Benefits were not included in the scope of the project.

Issue-based forecast capabilities
Not Applicable (NA). Forecast capabilities were not included in the scope of the project.

Tools, technologies and information services developed
Not Applicable (NA). Tools, technologies, and information services were not included in the scope of the project.

Publications
Technical Reports
Impacts of habitat quality on urchin gonad weight over the peak spring reproduction period. Ford T, Pondella DJ, Claisse JT, Williams JP 10/25/2011

Presentations
Powerpoint: All for Kelp and Kelp for All!! Tom Ford 9/26/11
Powerpoint: SMBRC Stewards of Santa Monica Bay. Lia Protopapadakis 9/28/2011

Theses Projects
Senior Thesis on *Strongylocentrotus purpurtatus* and *S. franciscanus.* Coleman DJ, Protopapadakis L, Dorsey J. Loyola Marymount University 5/5/2011

Senior Thesis: Urchin Gonad Indices. Hall N, Protopapadakis L. Loyola Marymount University 5/5/2011

Miscellaneous documents (not listed above).
Urchin Gonad Project for Knatz. Protopapadakis L, Ford T, Pondella DJ. 10/25/2011. Handout

MEDIA COVERAGE:
Not Applicable (NA). Seeking media coverage was not part of the project scope.

DISSEMINATION OF RESULTS:
Results will be disseminated through peer-reviewed journals (in preparation), oral presentations at conferences (SCAS), and project partner websites.

COOPERATING ORGANIZATIONS:
Federal
The Montrose Settlements Restoration Program (MSRP) and the NOAA Southwest Restoration Center assisted the project partners with developing the methods so that the results of this project can inform future projects contemplated by the MSRP and Restoration Center.

Regional
Not Applicable

State
Santa Monica Bay Restoration Commission is cooperates with the Santa Monica Bay Restoration Foundation on all its projects.

Nongovernment
Santa Monica Bay Restoration Foundation, Santa Monica Baykeeper.

International
Not Applicable.

Academic
Occidental College; Loyola Marymount University

INTERNATIONAL IMPLICATIONS:
Nearshore rocky reef habitat in Australia, New Zealand, South Africa, Chile, Canada, Japan, Russian and Norway has documented urchin barrens. Fisheries for urchins and abalone in Australia, New Zealand and Chile are engaged in revised management strategies to maintain stable kelp forests, decrease urchin barrens and enable sustainable fisheries. The methods and results associated with this project would be applicable in other areas with kelp forests and kelp-dependent fisheries.

AWARDS:
NA

KEYWORDS:
sea urchin, kelp forest, urchin barren, gonad index, gonad indices, top down control, secondary production

PATENTS:
NA

FOR ALL STUDENTS SUPPORTED BY THIS GRANT, PLEASE LIST:
Volunteer Count = 13

Graduate Student Info
None listed