PROYECTO Nº: 3110021
DURACIÓN: 3 años
AÑO ETAPA: 2013
TÍTULO PROYECTO: CLIMATE FORCING OF LOCAL AND REGIONAL MECHANISMS OF COEXISTENCE BETWEEN TWO BARNACLES (JEHLIUS CIRRATUS AND NOTOCHTHAMALUS SCABROSUS) ALONG THE COAST OF CHILE

DISCIPLINA PRINCIPAL: ECOLOGIA Y CIENCIAS AMBIENTALES
GRUPO DE ESTUDIO: BIOLOGIA 1
INVESTIGADOR(A) RESPONSABLE: JENNIFER LYNN SHINEN COFFIN
DIRECCIÓN: COMUNA:
CIUDAD: El Tabo
REGION: V REGION

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### OBJETIVOS

Cumplimiento de los Objetivos planteados en la etapa final, o pendientes de cumplir. Recuerde que en esta sección debe referirse a objetivos desarrollados, NO listar actividades desarrolladas.

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<td>1</td>
<td>Maintain monitoring program to assess how climate variability at local and regional scales (1m-100kms) may affect the distribution and abundance of the intertidal barnacles, Jehlius cirratus and Notochthamalus scabrosus, via species-specific demographic responses to intertidal and oceanic temperature gradients.</td>
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<td>Complete and evaluate experiment investigating how climate variability may affect species-specific recruitment rates of Jehlius and Notochthamalus.</td>
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<td>Conduct broad-scale intertidal surveys of barnacle communities along the greater coast of Chile and evaluate if local, regional, and inter-regional variability in climate and biotic interactions create predictable patterns of coexistence of Jehlius and Notochthamalus across a larger portion of their geographic range</td>
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Otro(s) aspecto(s) que Ud. considere importante(s) en la evaluación del cumplimiento de objetivos planteados en la propuesta original o en las modificaciones autorizadas por los Consejos.
RESULTS OBTAINED:
For each specific goal, describe or summarize the results obtained. Relate each one to work already published and/or manuscripts submitted. In the Annex section include additional information deemed pertinent and relevant to the evaluation process. The maximum length for this section is 5 pages. (Arial or Verdana, font size 10).

As the final stage of this project draws to a close, we have a greater understanding of how climate variability, in concert with variable recruitment and biotic interactions, influences the coexistence between two chthamalid barnacles, *Jehlius cirratus* and *Notochthamalus scabrosus*, along the coast of central Chile. Monitoring efforts established in 2010-2011 have continued to date, the settlement experiment allowed to continue into 2013 has been completed, and multiregional surveys of barnacles and intertidal communities have been conducted. Overall, we have found that *Jehlius* and *Notochthamalus* may be differently affected by climate variability, mediated principally by differences in recruitment success, driven primarily by near-shore oceanographic processes that differ among sites and geographical regions. These findings are consistent with our conclusions from previous analyses that *Jehlius* and *Notochthamalus* coexist through primarily neutral means and that their local patterns of abundance is largely determined by a recruitment lottery for space.

**Objective 1. How does climate variability affect the distribution and abundance of *Jehlius* and *Notochthamalus* via species-specific demographic responses to intertidal and oceanic temperature gradients?**

1a. **MONITORING EFFORTS**

**Main objective:** Local barnacle populations have been continuously monitored inside previously established permanent plots at three tidal elevations and at seven sites centrally located on the coast of Chile at 5-6 month intervals. Plots at different tidal elevations are exposed to varying aerial temperatures during low tide, which are in turn nested within sites that correspond to a range of cooler and warmer waters associated with variable upwelling conditions during tidal immersion and prevailing weather patterns during emersion, creating a natural “laboratory” in which we can observe species-specific responses to locally and regionally variable climatic conditions.

**General methodology:** From photo analysis, species-specific abundance and sizes are assessed, and then used to extrapolate local population and individual growth rates. Baseline, species-specific recruitment rates of *Jehlius* and *Notochthamalus* at all centrally located study sites are assessed monthly in collaboration with Dr. Sergio Navarrete as part of a long-term recruitment monitoring program established in 1997. In addition to this biological monitoring, physical monitoring of local conditions has been established via temperature loggers installed at the upper vertical range of the barnacle zone, at each of the seven sites, concurrent with barnacle monitoring plots. Loggers are affixed directly to the rock surface and register temperature (°C) at 10 minute intervals, thus providing estimates of daily maximum and minimum temperatures that barnacles experience associated with hot, midday low tides and cold immersion during high tide, respectively.

**Results:** From both monitoring plots and recruitment monitoring, we have established the functional ecological 'equivalency' of *Jehlius* and *Notochthamalus*, where both barnacles respond similarly to local environmental variability and are equal competitors across all sites and tidal elevations (Shinen & Navarrete, 2014). *In situ* temperature monitoring showed similar, cooler temperature profiles among study sites during fall and winter months, with Matanzas and Punta Talca being the coolest and warmest, respectively (Annex Table 1). Over spring and summer months, however, differences bewteen regions and among sites became more appaarent. Northern sites reached higher daily maximum temperatures, though Guanaqueros remained cooler. At Southern sites, daily maximum temperatures were several degrees cooler, especially at El Quisco. From barnacle plots, despite equal competitive abilities, we have observed shifts in the relative dominance of species from *Jehlius* toward *Notochthamalus* in the high and mid barnacle zones at 3 sites across the study region, Temblador, Guanaqueros, and Pichilemu (Annex Fig. 1). At the northern sites, Temblador and Guanaqueros, these shifts in dominance are a result of increased recruitment and abundance of *Notochthamalus*, whereas at Pichilemu, the shift in dominance is the result of a steady decline in abundance of both species, but especially of *Jehlius* (Annex Fig. 2ab). At the remaining 4 sites, Los Molles, Montemar, ECIM Norte, and Matanzas, the relative
proportions of barnacles at 3 tidal elevations has been more or less consistent over the past five years of monitoring. The “recruitment failure” or significant decrease in recruitment of both Jehlius and Notochthamalus at all sites south of the 32° latitudinal biogeographic break has continued into 2013 (Annex Fig. 3).

1b. RECRUITMENT EXPERIMENT

Main objective: After barnacle larvae arrive to a suitable intertidal shore, settle, and metamorphose into juvenile barnacles, or “spat,” the thermal conditions during tidal emersion cause high mortality and a species might be more susceptible than the other. Because of the recruitment failure at southern study sites, we could not obtain barnacle recruits settled onto mussel shells (a phenomenon which occurs predominately at sites south of 32° where intertidal mussels are more abundant) to perform translocation experiments, as we had planned. Instead, we investigated how recruitment varies in different thermal environments with a novel recruitment collector design, where the temperatures of artificial substrates are manipulated through the use of dark and light colored plastic surfaces.

General methodology: In collaboration with Rebecca Kordas, a Ph.D. student from the University of British Columbia, we constructed white and black PVC thermal collecting plates, standardized by a settlement surface (an opaque, textured marine epoxy) at the center of each plate. Eight pairs of plates were installed in the mid barnacle zones at Temblador, Guanaqueros, ECIM, and Matanzas, capturing regions north and south of the 32° latitudinal break as well as sites more and less directly influenced by coastal upwelling. During the spring and summer months of 2012, surface temperatures of representative plates were monitored in situ with ibutton temperature loggers. Recruitment of barnacles onto plates was monitored approximately every 5-6 months after plates were initially installed in the summer of 2012 and until they were finally removed in fall of 2014.

Results: At northern sites (Temblador and Guanaqueros), black plates on average were only 1-2° C warmer than white plates over the course of spring and summer days (Annex Fig.4). However black plates reached maximum surface temperatures 3-6° C higher than their white counterparts. At the southern sites (ECIM Norte and Matanzas), temperature differences were less pronounced, over the season, but were most apparent in November and December (Annex Fig. 4). Consistent with recruitment monitoring, very little recruitment was observed at the two southern sites, ECIM and Matanzas, and the northern site, Guanaqueros, while much greater recruitment was observed onto plates at Temblador (Annex Fig. 5). At the two northern sites, no differences in abundance of Jehlius or Notochthamalus were observed between black and white plates until the final sampling period, when Notochthamalus experienced significantly higher reductions on the hotter black plates. This suggests that the thermal conditions created by our settlement plates likely affect the settlement of both species similarly, but the post recruitment survival of larger juvenile Notochthamalus may be slightly more sensitive to the warmer conditions on the black plates. At the southern sites, we observed a slightly greater abundance of both Jehlius and Notochthamalus on the white plates rather than black plates, with an even greater number of Jehlius on white plates at ECIM Norte (Annex Fig. 5), but caution should be taken interpreting these latter results because of the long time lapse between observations. As with patterns observed at the northern sites, these differences were most apparent in fall 2014. Overall these results suggest that neither species’ settlement preference or early post-settlement survival is affected by the thermal conditions created by the two plate types, but that perhaps biotic conditions on the plates some time after settlement (increased barnacle density or accumulation and succession of other invertebrate and algal species) interact with thermal conditions to favor or disfavor recruitment and survival of barnacles. For instance, we also monitored the relative abundance of all other invertebrate and algal species that recruited to the thermal settlement plates and observed the most pronounced differences in the fall of 2014 on white plates located at southern sites (Annex Figs. 6, 7). Similar to Jehlius and Notochthamalus abundance, we found greater species richness and abundance of littorine snails at both ECIM Norte and Matanzas on white plates than black plates, and greater species diversity on white plates at Matanzas. No differences in sessile species richness, species diversity or mobile herbivore abundance were found between black and white plates at the two northern sites. Further experimentation is necessary to determine any causation among these patterns, but it is possible that species rich algal communities accumulating on southern white plates further alter thermal conditions favorably for both Jehlius and Notochthamalus.
Conclusions from Objective 1: In general, we found that adult Jehlius and Notochthamalus respond similarly to climate variation at nearly every local scale (among tidal elevations) and regional scale (among sites), suggesting that although climate change may have important impacts for local chthamalid barnacle abundance, the overall competitive interactions between the two species will likely remain unchanged. However, climate does appear to have a strong effect on recruitment success, such that cooler environments favor Notochthamalus more so than Jehlius, though both species reacted favorably to cooler conditions. We observed particularly dramatic consequences of this effect at the coolest site (Pichilemu) where prolonged recruitment failure occurred in concert with overall adult mortality, producing a shift toward Notochthamalus dominance.

Objective 2. (Completed in 2012)

Objective 3. (Completed in 2012)

Objective 4. Does climate variability create predictable patterns of coexistence between Jehlius and Notochthamalus at local scales or across geographic ranges?

Main objective: We conducted community surveys along the coast of Chile to investigate the larger-scale patterns of Jehlius and Notochthamalus abundance. Sites and regions were chosen to capture representative latitudinal variation in aerial temperatures and coastal features that can be useful in predicting the influence of upwelling and sea-surface temperature. Our surveys also sought to identify any associations of barnacle species abundance, sizes, or patterns of zonation with other dominant taxonomic or trophic functional groups of intertidal organisms. Additionally, the surveys of barnacle distribution and abundance throughout the Chilean coast were not planned until year 3, additional logistic support from the sponsoring investigator, Sergio Navarrete, and from a Fullbright fellow, Emily Lamb (USA), have provided for additional and exciting advances since our initial headstart in year 1 of this project. Vertical transect surveys, which were began in 2010, at 11 sites in central Chile, were repeated at some sites in the summer months of 2011, 2012, and 2013. This fortuitous repetition of surveys has allowed us to gather valuable information as to how patterns in species dominance vary across the tidal gradient from year to year and through our primary study region.

General methodology: In spring and summer months, three vertical transects were established traversing the shore from the upper limit of the barnacle zone to the low zone dominated by Lessonia at seven geographic regions throughout Chile; Iquique, Antofagasta, Coquimbo, Valparaiso, O’Higgins, Concepción, and Valdivia. The total length of each transect varied within among sites, as we standardized our sampling by subdividing each length into 10 transect intervals. A photo of a 10x10cm plot was taken at each transect interval. From the photos, individual adults of Jehlius and Notochthamalus were counted as well as the total number of barnacle recruits (unidentified Jehlius and Notochthamalus). We also estimated the percent cover for all other sessile algal and invertebrate species present and counted all other mobile herbivores present within each plot. To create an index of zonation between Jehlius and Notochthamalus, we calculated a transition rate of species dominance from the high shore to the low shore from the slope of the best fit line relating the relative proportion of Jehlius individuals to the total number of barnacles in each plot (J/(J+N)) with the relative shore height (transect interval). Barnacle sizes were estimated by measuring carino-rostral length.

Results: Surveys across the greater Chilean coast showed differences in barnacle abundance at both regional and local (site) scales (Annex Fig. 8). Within the two most extreme regions surveyed, Iquique and Valdivia, total chthamalid barnacle cover was similar among sites, regardless of relative exposure to the open coast at each locality, though total cover was much greater in the north. Barnacles were more abundant at exposed sites than protected sites in Antofagasta and Concepcion. Within the more centrally located regions of Coquimbo, Valparaiso, and O’Higgins, total barnacle cover was greater at protected sites that were less under the direct influence of coastal upwelling. In general, and across all regions survey, sharper zonation (i.e. dominance transition rate of Jehlius to Notochthamalus across the tidal range) was observed at cooler, exposed sites, with no strong latitudinal trend present (Annex Fig. 9). Sizes of Jehlius and Notochthamalus were positively correlated across all regions, with the exception of Valdivia, suggesting that both barnacles are similarly affected by varying conditions among sites within each region (Annex Fig. 10). However, size relationships with tidal elevation varied among regions.
(Annex Table 2), reflecting differences in recruitment and growth rates along the coast. Forty-two additional species were identified along the vertical transect surveys and partitioned into six functional groups (Annex Table 3).

Percent cover of both *Jehlius* and *Notochthamalus*, pooled together, was positively correlated with cover of ephemeral, crustose, and articulated algae, but only at sites within the Concepción region (Annex Table 4). No other correlations among barnacles and functional groups of other sessile species were found at the regional level. Across the entire coast, the transition rate of *Jehlius* to *Notochthamalus* was negatively correlated with the percent cover of chamalids (Annex Fig. 11), suggesting that zonation is sharpest when barnacle density is greatest. Transition rates were also positively correlated to the percent cover of bare rock, further indicating that competition for space strongly influences patterns of coexistence such that *Notochthamalus* is favored over *Jehlius* lower on the shore when barnacles and all other sessile space holders are most dense. Since adult barnacles are equal competitors and not sensitive to regionally varying climatic conditions, this further supports our conclusion that recent settlers are more influenced by locally varying climate, i.e. near-shore oceanographic conditions and overall competition for space. We also found transitions rate to be negatively correlated to the cover of articulated algae, but species within this functional group were not commonly observed throughout the study region and the pattern was largely driven surveys in Antofagasta and to a lesser extent, in Concepción (Annex Table 5). Contrary to previous work, we did not find transition rates to be correlated to with the abundance of chthamalid recruits, but further study in this area is needed to determine if slight differences in methodologies are responsible for the conflicting results.

Our analyses from surveys conducted over multiple years within our central study regions (Coquimbo, Valparaiso, and O'Higgins) showed that the local abundances of chthamalids stayed more or less consistent from year to year (Annex Fig. 12), even at southern sites experiencing prolonged recruitment failure. Transition rates, however, appear to be more variable from year to year at some sites, particularly where total barnacle abundance is lower (Annex Fig. 13).

**Conclusiones from Objective 4:** Overall, regional surveys showed a lack of a strong latitudinal trend in barnacle abundance or patterns of coexistence, despite large variation in aerial temperatures from Iquique in the north to Valdivia in south. Within some regions, however, we found evidence of stronger zonation at sites more exposed to the open coast and stronger upwelling conditions (cooler sea-surface temperatures). Patterns of coexistence between *Jehlius* and *Notochthamalus* were also correlated to indicators of competition for space on the shore, such that zonation becomes sharper as total barnacle abundance increases and primary space becomes limiting. However, adult barnacles are equal competitors and not sensitive to regionally varying climatic conditions, suggesting that recent settlers are more influenced by locally varying climate, i.e. near-shore oceanographic conditions and overall competition for space. We found that *Jehlius* and *Notochthamalus* are not sensitive to regionally varying climatic conditions, but are more influenced by locally varying climate, i.e. near-shore oceanographic conditions.
OTHER ACHIEVEMENTS OF THE PROJECT:
- Research visit(s) to other institution(s).
- Outreach activities related to the project’s main topic.
- Any other contribution, not addressed elsewhere, that you consider important.

The maximum length for this section is 1 page. (Arial or Verdana, font size 10).

As mentioned in previous reports, an important outcome of this project has been the research experience and professional development opportunities afforded to a number of international students. I am quite pleased to report that all students that have been involved in this body of work have gone on to further their careers and education to great success. Emily Lamb, a former US Fulbright scholar, is now in a Master’s program at Duke University, USA. Simon Karythis, a former post-graduate exchange student from England, is now in a Master’s program at the University of Bangor, Wales, UK. Rebecca Kordas, a former graduate student from the University of British Columbia, Canada, has won a prestigious National Science Foundation International Postdoctoral Fellowship and will be continuing her studies on climate change on marine ecosystems at the Imperial College of London, UK.

In August 2014, as part of my visit to California, USA, to attend the annual meeting of the Ecological Society of America, I was an invited speaker for a public seminar series, “Science Uncorked,” through the Bodega Marine Laboratory of the University of California Davis. My presentation, “Rocky intertidal adventures in Chile: a history of one of the world’s first marine reserves and how climate change may affect some of its inhabitants,” was an excellent experience in diffusion and community outreach and generated an exciting discussion and public interest about how climate change along the coast of Chile may be impacting marine species and local fisheries.
EVALUATION REPORT FROM POSTDOCTORAL RESEARCHER SPONSOR

SPONSOR NAME: Sergio Navarrete

The research conducted by Dr. Jennifer Shinen, supported by her Fondecyt Postdoctoral grant, is impressive both by the geographically extensive and locally intensive scientific information she managed to generate, and by the quality and novelty of the studies she conducted. Despite the interruptions in her research program (due to pre- and post-natal leaves), she was able to maintain the experimental and monitoring program goals she set out in her original proposal. As a result, she now has one of the most impressive datasets and scientific knowledge about marine species that compete for space that I am aware of. The experiments conducted at multiple sites to evaluate specific aspects of this competitive system, as well as the experimental protocols to manipulate in situ temperatures, to which settling larvae are exposed to, have few parallels in the world.

Importantly, the information gathered through field observations, laboratory experiments and field manipulations demonstrate that these two barnacle species, Jehlius cirratus and Notochthamalus scabrosus, coexist on the rocky shore, despite intense competition for space, thanks to their “equality”, rather than due to niche differences. In this manner and to my knowledge, Jenna’s results and her papers become only the second system, next to Siepilsky & McPeak’s damselflies, in which carefully designed experimental manipulations have demonstrated that nearly neutral dynamics favor coexistence in the real world. Notably, her results have been obtained in an ecosystem, the rocky intertidal shore, where examples of competitive hierarchies and local coexistence through either resource partitioning (e.g. zonation) or keystone predation fill the pages of many ecology textbooks. Her results show that within the same community some species manage to coexist owing to being very similar.

Although Jennifer already published papers with her results, all in international ISI journals and including one in the prestigious journal American Naturalists, I feel she is just scratching the surface of the rich databases generated during the grant. The laboratory and field experiments designed to evaluate the role of predation in coexistence and differential intertidal distribution between these barnacles, the results on geographic variability in absolute and relative abundances, and the experimental responses to locally-manipulated climate conditions will undoubtedly generate new publications and Jenna is working toward that goal.

So, I am very happy with the work Jennifer was able to accomplish and I can only hope her new results see the light soon in the scientific literature.

Sponsor signature

Date: ___October 30th, 2014_____________
### ARTÍCULOS

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<td>Lamb, EA.; Leslie, HM.; Shinen, JL.</td>
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OTRAS PUBLICACIONES / PRODUCTOS

Sin información ingresada.

CONGRESOS

N° : 1
Autor (a)(es/as) : Shinen, JL.; Navarrete, SA.
Título (Idioma original) : Barnacle lotteries and competitive equivalence: the roles of variable recruitment and interference on species coexistence
Nombre del Congreso : International Temperate Reefs Symposium
País : REINO UNIDO DE GB E IRLANDA DEL NORTE
Ciudad : Plymouth
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Fecha Término : 01/07/2011
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N° : 2
Autor (a)(es/as) : Karythis, S.; Medrano, A.; Shinen, JL.; Navarrete, SA.
Título (Idioma original) : Influencia de la depredación sobre la distribución relativa de dos especies de cirripedios en la costa de Chile
Nombre del Congreso : I Simposio del Centro de Conservación Marina
País : CHILE
Ciudad : Las Cruces
Fecha Inicio : 24/10/2013
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Autor (a)(es/as): Karythis, S; Medrano, A.; Shinen, JL.; Navarrete, SA.
Título (Idioma original): Can predation play a role on the relative abundances of two intertidal chthamalid barnacles that compete for space
Nombre del Congreso: V Reunión Binacional de Ecología
País: CHILE
Ciudad: Puerto Varas
Fecha Inicio: 03/11/2013
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Autor (a)(es/as): Shinen, JL.; Kordas, RL.; Navarrete, SA.
Título (Idioma original): Weathering it together: Experimental test of the effect of climate variability on the neutral coexistence of barnacle competitors on Chilean rocky shores
Nombre del Congreso: 99th Annual Meeting of the Ecological Society of America
País: ESTADOS UNIDOS DE AMERICA
Ciudad: Sacramento
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