Estimating productivity of Pacific coral reef fisheries

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Project Summary:

The goal of this project was to determine the stock size, stock condition, and fisheries productivity of the most abundant coral reef fishes in the tropical Pacific. To accomplish the overall goal, this project was organized into three sections: *(1) Life-History Parameters of Key Species and Functional Groups; (2) Fisheries Productivity – Single Species Models; and (3) Fisheries Productivity – Multiple Species Models*. Within each section a series of activities were carried out and products were produced in order to meet the project objectives. A major component of this project included the identification or collection of life-history information for some of the most abundant coral reef fishes from the central Pacific. The initial target was set at 100 species and we exceeded our goals in many aspects by identifying 120 species where life-history information was currently available but not synthesized into a single database. We made monumental efforts to collect additional life-history parameters for 33 species where information was non-existent for the central Pacific. We performed an initial size-based assessment of fish assemblages from the US Pacific Islands and continue towards developing metrics for assessing coral reef fisheries productivity. Lastly, as this project matured we recognized an opportunity to mentor students and provide them with a firsthand look into the field of coral reef ecology. Although this serves as the final report for the NOAA CRCP Award, the products and information produced as a result of this award will continue to develop and the information provided within will provide scientists and managers with the tools necessary for gaining insights into the coral fisheries productivity and identifying metrics critical for effective ecosystem-based management. The following is a detailed description of the activities completed and the products created during the funding period.

1) Life-History Parameters of Key Species and Functional Groups –

A major goal of this project was to identify or obtain fundamental life-history information for 100 coral reef fishes from the central Pacific. In order to reach this goal we set out to: i) conduct a thorough search through published and online databases (e.g. Fishbase) to identify life history information for coral reef fishes from the central Pacific, and ii) For species where life-history parameters were not available we conducted multiple shore or ship-based field expeditions. During these expeditions we performed targeted collections of the most abundant coral reef fish species across multiple trophic groups to create a comprehensive life-history database for the central tropical Pacific.

i) Life-History Parameters of Key Species and Functional Groups – An extensive search of the literature for detailed life-history information for key species throughout the tropical Pacific, was collated and summarized in a database. We found length-weight parameters for 810 coral reef associated species, with 357 of these species represented by more than one estimate of parameters. Further, we have found parameter estimates for von Bertalanffy growth functions (VBGF; relating age to length) for 120 coral reef associated species. A summary of the parameters obtained is provided in Table 1. A detailed summary of this life-history information was provided to the Coral Reef Ecosystem Division and the Stock Assessment and Fisheries Research and Monitoring Division at the NOAA PIFSC in Honolulu Hawaii.

Table 1. Summary of the number of fish species where length-weight parameters (intercept: α and exponent: β) and the life history parameters (theoretical maximum length: L_∞ and growth rate coefficient: K) have been identified from the literature and online sources. Individual fish species are grouped by Family (row) and basic taxonomic group (column).

Family	Top Predator	Carnivore	Herbivore	Piscivore	Planktivore	Total
Acanthuridae			15		5	20
Balistidae		2				2
Carangidae	7			2	3	12
Carcharhinidae	3					3
Chaetodontidae		4			1	5
Chanidae			1			1
Haemulidae		2				2
Holocentridae		3			1	4
Kyphosidae			1			1
Labridae		6			1	7
Lethrinidae	1	5		1		7
Lutjanidae	2	3		1		6
Mullidae		4				4
Pomacentridae		1	4		7	12
Scaridae		1	10			11
Serranidae	3			7		10
Siganidae			2			2
Sphyraenidae	3					3
Synodontidae				1		1
Total	19	4	33	12		113

ii) In addition to the extensive literature search, this project set out to collect life-history parameters for species where parameters were unavailable for the central Pacific. Over the course of the project period we have obtained life-history parameters for 33 species and includes 4160 individual specimens (Table 2). This represents an enormous undertaking for the SIO Life History Lab as each fish takes nearly 20 minutes to collect morphometric information and complete the dissection of organs (liver, stomach, gonads, otoliths) and otoliths. All samples have been dissected and prepared for aging, with approximately 10% of the individuals aged to date. This represents over 1100 hours of work. While our expectation was to complete this work over the period of this award, the high time demand limited us to completing only this subset of the total effort to date. Using other funds, we are completing the laboratory analyses, with a goal of final completion before the end of 2012.

Table 2. Summary of collection efforts for fish species from the central Pacific. Trophic group assignments: Apex= Apex Predator, C=Corallivore, H= Herbivore, Mid= Mid-level Carnivore, Pisc= Piscivore, Z=Zooplanktivore.

Species	Family	Trophic	Total
Ctenochaetus marginatus	Acanthuridae	H	411
Acanthurus nigricans	Acanthuridae	H	373
Acanthurus olivaceus	Acanthuridae	H	99
Acanthurus triostegus	Acanthuridae	H	26
Sufflamen chrysopterum	Balistidae	Mid	71
Chaetodon lunulatus	Chaetodontidae	C	23
Chaetodon auriga	Chaetodontidae	Mid	16
Chaetodon ornatissimus	Chaetodontidae	C	12
Paracirrhites arcatus	Cirrhitidae	Mid	298
Cirrhitichthys oxycephalus	Cirrhitidae	Mid	55
Paracirrhites forsteri	Cirrhitidae	Pisc	76
Neoniphon sammara	Holocentridae	Mid	31
Thalassoma amblycephalum	Labridae	Z	47
Halichoeres hortulanus	Labridae	Mid	31
Thalassoma lunare	Labridae	Z	28
Halichoeres trimaculatus	Labridae	Mid	17
Monotaxis grandoculis	Lethrinidae	Mid	69
Lutjanus bohar	Lutjanidae	Apex	234
Lutjanus fulvus	Lutjanidae	Mid	70
Lutjanus kasmira	Lutjanidae	Mid	28
Aphareus furca	Lutjanidae	Pisc	20
Lutjanus gibbus	Lutjanidae	Mid	63
Parupeneus multifasciatus	Mullidae	Mid	83
Centropyge flavissima	Pomacanthidae	H	51
Stegastes aureus	Pomacentridae	H	362
Plectroglyphidodon dickii	Pomacentridae	C	127
Chromis margaritifer	Pomacentridae	Z	396
Pomacentrus coelestis	Pomacentridae	Z	136
Pseudanthias dispar	Serranidae	Z	162
Cephalopholis urodeta	Serranidae	Pisc	307
Cephalopholis argus	Serranidae	Apex	117
Pseudanthias cooperi	Serranidae	Z	116
Pseudanthias bartlettorum	Serranidae	Z	205
		Total	**4160**

iii) Collecting life-history parameters for species where published information was lacking represented a massive undertaking. Collection of specimens in the field and subsequent processing was accomplished by enlisting the assistance of undergraduate students as well as recent graduates who were looking for some hands on experience. In order to make the experience mutually beneficial, we encouraged lab volunteers and employees to take on independent research projects that they applied as credit towards their degree or towards future graduate work. This provided mentoring opportunity for the PI (Sandin) and graduate students, maximized the utility of every specimen collected, and increased the skills and knowledgebase of junior scientists in the field of coral reef fish ecology. During this project a total of 21 volunteers worked in the lab becoming proficient in demographic and life-history techniques (Figure 1). A total of 8 students worked with the PI and graduate students to develop and successfully complete an independent research project involving fish specimens from the central Pacific. Two students took their independent research projects a step further and are now pursuing additional graduate work incorporating samples or data collected with support from this NOAA CRCP award.

Using life-history information collected from 2 islands from the central Pacific with differing levels of fishing pressure we examined the indirect effects of fishing on the energy allocation of in non-targeted species (Ruttenberg et al 2011, Walsh et al. 2012). As sites with greater predatory fish biomass body condition and liver mass was low compared to sites where predators were less abundant. Alternatively, reproductive potential was higher at sites with higher predatory fish biomass. Further investigation into the indirect effects of predators is warranted and efforts to perform a larger assessment are underway.

Estimating productivity of Pacific coral reef fisheries

Figure: 1. Volunteers and graduate students working in the Life History Lab at the Scripps Institution of Oceanography.

2) Fisheries Productivity - Single Species Models –

It is widely known that fisheries alter the stock size and size-structure of the fish community through the direct extraction of targeted species. Therefore, size-based assessments of the fish community provide valuable insights into the potential productivity and community responses to exploitation. The goal of this section of the project was to calculate metrics important for assessing exploitation levels of coral reef fishes from the central tropical Pacific. To accomplish this we divided this section of the project into three parts: i) Identify fisheries targets for the region, ii) Perform and analysis of the size-structure of fish assemblages for the US Pacific Islands, and iii) Utilize life-history parameters to calculate fisheries productivity measurements.

i) The complexity of coral reef fisheries provides many challenges particularly due to the lack of information pertaining to catch. There is currently a lack of data indentifying which species are targeted. Working with scientists from the Socioeconomics Division and the Western Pacific Fisheries Information Network (WPacFIN), at the NOAA Pacific Islands Fisheries Science Center (PIFSC) we identified all available information related to coral reef/nearshore fisheries catch for the US Pacific Islands. Catch data collected through creel surveys were obtained for the Hawaiian Islands (1966-2009), American Samoa (1986-2009), Guam (1982-2009), and the Commonwealth of the Northern Mariana Islands (2000-2009). The data represent the best available catch for the US Pacific Islands. Using these data, we created a database standardizing catch statistics as: percent occurrence, number of years in catch, frequency of occurrence, and total biomass (kg) of each species by region. The database product was given to the NOAA PIFSC for initial evaluation.

ii) Using fishery independent data collected as part of the NOAA Pacific RAMP we performed an assessment of IUCN Red Listed species, many of which are particularly vulnerable to overfishing (Zgliczynski et al. *in review*). From this assessment key findings emerged, a) Mean abundances of Red-listed species significantly differed between uninhabited and inhabited islands, b) Abundances were greater in uninhabited versus inhabited regions, and c) The greatest diversity and abundance of IUCN Red-listed species were observed at remote and uninhabited islands of the central and western Pacific. In addition to this assessment of targeted species we also collaborated with members of CRED to describe the broad ecological effects of humans on fish assemblages (Williams et al. 2011). At sites where human population densities were high the mean biomass of the fish assemblage was low with few top predators. Lastly, we performed a preliminary evaluation of the assemblage-wide relationships between log_{10}-transformed biomass density and fish size for the 4 US Pacific Island regions (Figure 2). In general, the uninhabited islands within each region exhibited biomass densities concentrated in larger size classes with less negative regression slopes compared to inhabited islands. Additionally, inhabited islands tended to exhibit smaller size ranges of fishes with smaller-bodied fishes contributing the greatest percentage to total fish biomass. This size-based assessment provides insights into the direct effects of fisheries exploitation on the size-structure of fish assemblages in the US Pacific Islands.

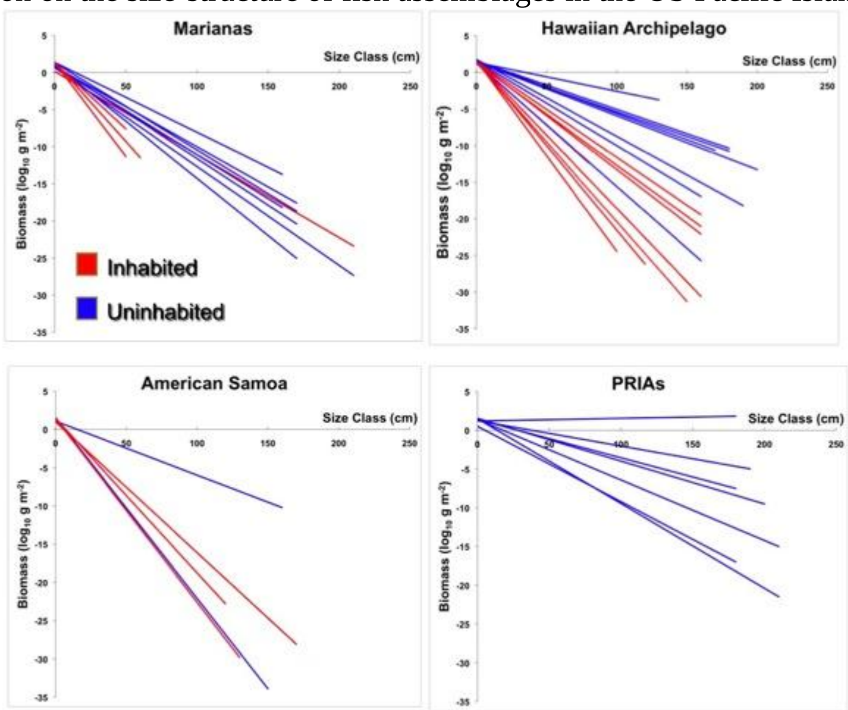

Figure 2. Biomass size spectra analysis for all fishes surveyed at 40 US Pacific Islands among 4 regions: Hawaiian Archipelago; Marianas Archipelago; Pacific Remote Island Areas (PRIAs); and American Samoa. Inhabited islands are identified with red lines and uninhabited islands are identified with blue lines.

iii) In addition to size-based based assessments of the fish assemblage this project aimed to identify and calculate metrics to assess exploitation levels of the fish stocks in the tropical Pacific. The biomass size spectra analysis provides a broad understanding of the potential effects of fisheries. The next logical step is to finish parameterizing models of fisheries productivity for the most commonly fished species of reef fish from the US Pacific. These models depend upon the comparison of fisheries structure between 'pristine' and unfished stocks (as found in the Marine National Monuments of the US Pacific) and those in the inhabited and actively fished stocks. Using the results of underwater visual assessments made during NOAA Pacific RAMP surveys we have begun to make efforts to identify stocks that can be considered ‘pristine’ for each region. These sites will serve as baseline conditions to which comparisons can be made to exploited stocks. Unfortunately, the time required to process fish samples and obtain life-history parameters exceeded our expectations and we were unable to complete a thorough assessment coral reef fish stocks in the tropical Pacific. We will complete this assessment in the course of the next 2 years.

3) Fisheries Productivity - Multiple Species Models –

We have made progress toward completing a study of the dynamical changes that occur with fishing across multi-species reef fish fisheries. Importantly, most community models of reef fisheries assume strong top-down control, of predators regulating the densities of prey. We have shown that in little-disturbed reef fisheries, the direction of control is instead from the bottom up (Sandin and Sala, 2012). This shift has important dynamical consequences in predicting fisheries yield and changes thereof. Using our novel statistical estimator, we are exploring realized patterns of fisheries productivity of a spectrum of multi-species fisheries. Combining data-derived estimates of life history parameters with empirical surveys of reef fish assemblage structure provides unique opportunities for advancing our understanding of reef fish productivity.

Importantly, these multi-species models have proven to be very data-demanding and computationally-intensive. Although we have made good progress in designing the mathematics and the coding, we are hesitant to finalize the implementation until we have all of the life history data fully analyzed. Completion of this module of the research, which is part of the PhD thesis of SIO student in the Sandin lab, will likely occur by the end of calendar year 2012.

Estimating productivity of Pacific coral reef fisheries

Project Relevant Publications:

Edwards, C.B., A.M. Friedlander, S.A. Sandin, I.D. Williams, B.J. Zgliczynski, J.E. Smith. In review. Global assessment of the status coral reef herbivorous fishes: evidence for fishing effects. Ecology Letters.

Ruttenberg, B.I., S.L. Hamilton, S.M. Walsh, M. Donovan, A. Friedlander, E. DeMartini, E. Sala, S.A. Sandin. 2011. Predator-induced demographic shifts in coral reef fish assemblages. PLoS ONE 6: e21062

Sandin, S.A. and E. Sala. 2012. Using successional theory to consider marine ecosystem health. Evolutionary Ecology 26: 435-448.

Walsh, S.M., S.L. Hamilton, B.I. Ruttenberg, M.K. Donovan, S.A. Sandin. 2012. Fishing top predators indirectly affects condition and reproduction in a reef-fish community. Journal of Fish Biology 80: 519-537.

Williams, I.D., B.M. Richards, S.A. Sandin, J.K. Baum, R.E. Schroeder, M.O. Nadon, B. Zgliczynski, P. Craig, J.L. McIlwain, R.E. Brainard. 2011. Differences in reef fish assemblages between populated and remote reef spanning multiple archipelagos across the Central and Western Pacific. Journal of Marine Biology 2011: 1-14.

Zgliczynski, B., Williams, I., Schroader, R., Nadon, M., Richards, B., Sandin, S. In review. Distribution and abundance of IUCN Red-listed Coral Reef Fishes in the US Pacific Islands.

Documents distributed to NOAA colleagues

1) Table of trophic designations for fish species in the central Pacific
    - Included as an appendix in Williams et al (2011), above

2) Detailed life history table for fish species from across the central Pacific
    - Distributed to Ivor Williams and Bob Humphreys (NOAA Pacific Islands Fisheries Science Center), and to Paul Dalzell (Western Pacific Regional Fisheries Management Council)
    - Note that this document is for internal use and is being prepared for publication for broader audiences

3) Review of the distribution of IUCN Red-Listed fish species from the US Pacific
    - For publication in peer-reviewed journal, with results disseminated among key NOAA individuals working with particular species from the study