Project Report: Genetic connectivity of Fijian coral reefs

Aims:

The goal of this project was to examine the genetic structure of coral reef populations both between Fiji and other areas of Melanesia and within the Fijian archipelago. To achieve these goals we have collected data from within nine sites within Fiji as well as from areas within the Solomon Islands and Papua New Guinea to give a proper geographic context.

We have collected and analyzed data from approximately 643 individuals from six species of fish and 413 individuals from five species of invertebrate from within Fiji. Additionally we are continuing to analyze data from two more species of fish as well as two species of sea cucumbers and two species of coral. Together these collections represent a large and ecologically diverse assemblage within which to evaluate the design of marine protected areas.

When examining the fish, we have found that for five species the Fijian populations are genetically distinct from those in Melanesia. When we examine fish populations within Fiji we see a general pattern of low genetic variation, however overlaid on this broad pattern there are several examples of small but significant barriers to gene flow. For the invertebrates, a similar pattern immerged. There was evidence or regional divergence (potentially cryptic speciation) within *Haptosquilla glyptocercus*, and strong regional genetic differentiation in *Linckia laevegata*, although no evidence of structure was seen in these species within the Fijian Archipelago. This complex picture means a nuanced approach to conservation is clearly warranted.

These findings of intra-archipelagic gene flow were contrasted by high degrees of genetic divergence between Fijian populations and conspecific populations from other areas of Melanesia. Taken together these findings indicate that the Fijian archipelago represents a largely cohesive functional unit in terms of genetic connectivity, but that at greater spatial scales, the islands of Fiji are unlikely to be connected to other reefs in the Indo Pacific for several of the species investigated. It is important to stress that while absence of genetic connectivity is conclusive proof of the absence of demographic connectivity, the high levels of genetic connectivity within the Fijian Archipelago cannot be assumed to mean that these populations enjoy high levels of demographic connectivity, as high genetic connectivity can result from levels of connectivity that are demographically insignificant. Thus, based on the precautionary principle we suggest that Fiji be treated as a unique conservation entity separate from other management plans in the Indo-Pacific region, as it is genetically and demographically isolated from other Indo-Pacific regions for a number of species. However, further research will be required within Fiji to determine the degree of demographic connectivity within this region. The recovery of subtle genetic structure in some fishes suggest that there may be limits to demographic connectivity within the Fijian Archipelago. A brief summary of our findings is presented in Table 1.

Table 1. Summary of Taxa, Sampling Effort and genetic structures

Taxon	Total Samples	Fijian Samples	W/in Fiji pattern	Southwest Pacific Endemic
Amblyglyphidodon orbicularis	102	102	slight barriers	Yes
Amphiprion melanopus	112	65	moderate barriers	Yes
Chrysiptera talboti	166	121	no barriers	Yes
Halichoeres hortulanus	137	108	no barriers	No
Pomacentrus callainus	99	99	slight barriers	Yes
Pomacentrus moluccensis	179	148	no barriers	Yes
Haptosquilla glyptocercus	427	62	no barriers	Yes
Linckia laevegata	>500	138	no barriers	no, but structure
Holothuria edulis	179	67	no barriers	no
Pocillopora damicornis	>500	144	Pending	pending

Field Collection:

Field collections funded under this grant have been carried out across most of Fiji and have been to each of four main regions (Viti Levu, Vanua Levu, Western Islands and Eastern Islands (Fig.1). We have sampled from at least one site within each one of these regions (Table 2).

Table 2. Sampling locations and sample size for within Fiji analyses. Note that for invertebrates, sample sizes exceed numbers analyzed due to difficulties in amplification and sequencing.

	West Isands		Viti Levu			Vanua Levu		Eastern Islands	
Species:	Mamanucas	Yasawas	Nananu-I-ra	Naigani	Ocean Pacific	Navatu	Naigigi	Naselesele	Kor
Amblyglyphidodon orbicularis (N=102)	23	14	23			14	9	19	
Amphiprion melanopus (N= 65)	15		7	11		6	8	18	
Chrysiptera talboti (N=121)	10	15	11	22	16	11	16	12	8
Halichoeres hortulanus (N=108)	9	11	9	10	12	15	17	19	6
Pomacentrus callainus (N=99)	17		13	24	12	10		23	
Pomacentrus moluccensis (N=148)	21		22	19	13	40	17	16	
Haptosquilla glyptocercus (N=95)	33			28	12		22		
Holothuria edulis (N=109)	7	10	23	18	24	3	22	2	
Linckia laevigata (N=209)	24	4	31	23	34	22	25	25	21
Pocilipora damicornis (N=144)	16		28	20	28	20	24	8	

Individual Results:

Fish:

This project identified a high degree of genetic uniqueness to the fishes of the Southwest Pacific. Two of the species we examined, *Amblyglyphidodon orbicularis* and *Pomacentrus callainus* have been recently described as endemic to the region, with both having been described as a southwest Pacific endemic form of a previously putative monospecific Indo-Pacific taxa. For the other species we examined, we found that with

one exception this pattern of Southwest Pacific endemism was repeated, despite a lack of formal taxonomic recognition. The one species which did display genetic homogeneity across Melanesia, *Halichoeres hortulanus*, has the largest range of any of the species examined, and only displays phylogeographic structure at the largest (intra-ocean) levels.

Within Fiji we found varying degrees of population subdivision, with three species displaying subdivision, and one consistent break among those species (Table 3). In three of the six species fully examined we found a small but significant break between the two farthest regions, the eastern and western islands. The fact that this pattern was repeated amongst several different species suggests that this break could represent an important conservation management tool for Fijian coastal resources.

Table 3. Percentage of fish species demonstrating significant pairwise population structure

	Western Islands	**Viti Levu**	**Vanua Levu**
Viti Levu	16.7%		
Vanua Levu	0.0%	0.0%	
Eastern Isalnds	50.0%	0.0%	16.7%

Amblyglyphidodon orbicularis:

Amb. orbicularis is a small plaktivorous schooling damselfish which is common throughout most of Fiji inhabiting thickets of branching *Acropora* coral at depths to 10m. It was previously considered part of a larger, widespread *Amb. leucogaster* species complex, however it was separated based on several meristic and morphological characteristics, which we have since validated using molecular techniques.

Within Fiji this species displays evidence of a small but significant break between the Eastern and Western Islands, all other comparisons revealed no signal of population structure. This was the only species however to display a signal of isolation by distance, suggesting that the observed genetic break was most likely do to the geographic separation of the samples.

Amphiprion melanopus:

A. melanopus is a charismatic anemonefish, and fairly common, if patchily distributed, member of the Fijian coral reefs. It is found in a variety of habitats, but often on the tops of reefs, or in shallow water. It is currently a member of the larger *A. ephippium* complex, however based on the substantial genetic divergence at both mitochondrial and nuclear genes; we are in the process of formally designating Fijian populations as a new species, *A. barberi*.

Within Fiji, *A. cf. melanopus* shows a similar pattern of genetic divergence between the eastern and western regions of Fiji, as the previous species. It also shows a unique pattern of divergence between the eastern islands and their neighbor Vanua Levu.

Chrysiptera talboti

C. talboti is a small and enigmatic planktivorous fish found throughout the Fiji on reef slopes and scree piles. The species is found throughout the Indo-Pacific, but the Fijian population has a small but diagnosable difference in the mtDNA sequence,

suggesting a recent, but independent evolutionary trajectory from other Melanesian populations.

As one would expect there is no significant population structure within Fiji.

Halichoeres hortulanus:

H. hortulanus is a common and easily recognized predatory member of coral reef communities ranging from French Polynesia to the Red Sea. While previous work has identified strong and significant population subdivision in this species, this break occurs far west of Fiji, in central Indonesia. Fijian populations share haplotypes with the populations in the Solomon Islands, and have no significant population structure between countries.

Based on these findings, it is not surprising that there was no evidence of population substructure within Fiji, and all areas have several shared haplotypes.

Pomacentrus callainus:

P. callainus is a small gregarious planktivorous damselfish, which is common in the shallow depths of patch reefs and reef tops. Until recently, *P. callainus* was considered to be a geographic variant of the widespread *P. lepidogenys*, however careful investigations have shown consistent differences in merisitcs and coloration that has lead to the elevation of the Fijian and Tongan populations to specific status.

Within Fiji we see a moderate level of population structure. As with *Amb. orbicularis* and *A. melanopus*, we see the Western Islands having small but significant differences when compared to the Eastern Islands, however *P. callainus* also displays an additional small but significant break between the Western Islands and Viti Levu.

Pomacentrus moluccensis:

Like *A. melanopus* and *C. talboti*, *P. moluccensis* is currently described as a broadly distributed species; however our genetic data suggests that the Fijian populations are highly divergent from those in the Solomon Islands, Papua New Guinea and Vanuatu. These data suggest that *P. moluccensis* populations in Fiji are reproductively isolated from the other conspecifics in Melanesia, and represent a unique evolutionary significant unit, and potentially a new species.

Within Fiji *P. moluccensis* is a relatively common fish found darting in and out of coral structure from shallows to depths of 20m. Despite the high levels of genetic divergence between Fiji and its neighbors, within Fiji, *P. moluccensis* displays remarkably little genetic variation, and subsequently there are no significant incidents of population subdivision within the archipelago.

Invertebrates:

Data from invertebrates show a similar pattern to those in fishes. There is strong evidence of regional isolation in the divergent lineage of the stomatopod *H. glyptocercus* as well as in the strong regional structure in *L. laevegata.* These results support the notion that Fiji is demographically and evolutionarily independent from populations in the Western Pacific. However, this was not true of all species as *H. edulis* did not exhibit these regional patterns of divergence.

Within Fiji, all species showed no evidence of isolation. Thus, while Fiji (and potentially other Central Pacific) populations should be considered independent in terms of management planning, there is insufficient evidence to comment on connectivity within the Fijian Archipelago. Although no clear genetic barriers exist, high genetic connectivity cannot be assumed to equate to high demographic connectivity. Demographic independence of regions within Fiji may still exist, despite the ability of our methods to discover them.

Haptosquilla glyptocercus

As with many of the fish species, *H. glyptocercus* had a reciprocally monophyletic lineage characteristic of Fijian populations. Subtle morphological differences suggest that these populations may represent a cryptic species. It is not clear whether this species is limited to Fiji or to the entire central Pacific region.

Despite evidence for genetic structure within other parts of its Indonesian range, there was no evidence for genetic structure within the Fijian Archipelago.

Linckia laevegata

Unlike many fish and *H. glyptocercus, L. laevegata* did not show a reciprocally monophyletic lineage in Fiji. However, there was strong evidence for regional genetic structure. Between Fiji and Indonesian populations Fst=0.48 and a total of 47% of the molecular variation in the data set was due to differences among these two regions.

This strong pattern of regional isolation contrasts with limited structure within Fiji. For Fiji analyses, there were no significant Fst values and 98% of all variation was contained at the population level

Holothuria edulis

The sea cucumber *H. edulis* did not show evidence of structure between Fiji and Indonesia. Neither did it show structure within Fiji. This result highlights that individual species have unique evolutionary history and demographics and that these differences must be accounted for in regional management planning

Pocillopora damicornis

Due to marker difficulties, data collection for *P. damicornis* are still underway. Results will be amended to this report, once available.

Science to Action:

One of the major aspects of this project is bringing the findings of the research to as broad a community of audiences as is possible. Therefore we travelled throughout Fiji to present a variety of lectures and informal discussions to a wide variety of resource users, government officials, non-government agencies, and academics. A summary of these activities is provided as an addendum to this report. In addition we have been partnering with local and international media agencies to disseminate the findings to an even larger segment of society. Finally, as 2008 is the International Year of the Reef, we are scheduling a large-scale public presentation in conjunction with a larger international campaign of reef conservation awareness. Results from this work were also presented at

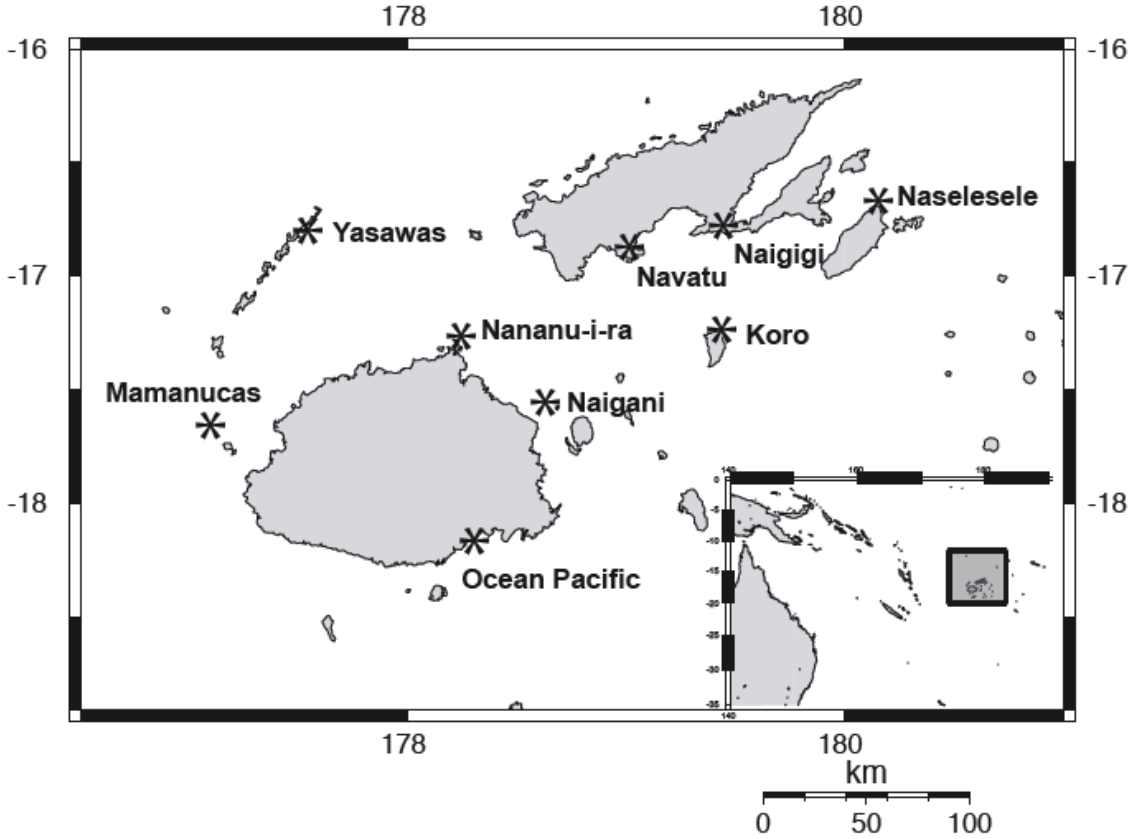
the 2008 International Coral Reef Symposium, highlighting the results of this work and of the CI MMAS program.

The local presentations are conducted in English, however we partnered with researchers from the Fiji Department of Fisheries to make sure that there will be translation into Fijian. This was especially important for the village sessions. During these sessions we had a half hour to hour presentation followed by a one to two hour question and answer session.

In addition to the oral presentations we have coupled with Partners in Community Development Fiji (PCDF) to produce two educational posters. In our experience we have found posters to be an effective means of long-term communication within the villages. They serve to reinforce the message delivered from the presentation, provide a striking visual aide for understanding, and provide contact information for local follow-up.

We have also been working to publish our findings in peer-reviewed journals. We have one manuscript, describing the genetic relationship of southwest Pacific endemics in press in *Conservation Biology*, which will most likely be the cover story in August 2008. A second manuscript describing the population genetics of species within Fiji is under preparation, and should be ready for submission to a major peer-reviewed journal by the end of the summer. Finally we have described two new species, including *A. barberi* as a direct result of this work.

Figure 1. Sampling areas within Fiji



Trip Report prepared by Josh Drew of Science-to-Action efforts in Fiji

Meetings:

Government: I met with several high-ranking individuals from the Fijian government including the Minister of Fisheries, the head of fisheries research, and the number two from the Ministry of Tourism. Additionally there were representatives from the CITES office as well as other government agencies.

I presented a 20 min PowerPoint talk first highlighting the usefulness of marine reserves and then showcasing the findings of my research, in particular the section regarding gene flow within Fiji and its application towards marine reserve design. The talk was well received and there was an extensive (>30 min.) question and answer session over tea following the presentation.

NGOs: I also gave a similar presentation in an informal setting to several representatives of the NGO, academic and US diplomatic community. Again this talk highlighted the science behind marine reserves as well as some of the findings of my research, including the extensive gene flow within Fiji and the presence of genetically differentiated populations within Fijian waters. The talk was well received and I had several positive conversations with a variety of audience members, who provided constructive feedback for further presentations.

Academic: I presented three lectures, two for Dr. Milika Naqasima-Sobey's classes (marine biology and general ecology) as well as Dr. Randy Thaman's island biogeography class at the University of the South Pacific. Two of the lectures were based on my dissertation defense, while the third (to the general ecology class) was about historical ecology and shifting baselines. I also gave a public presentation at the university to start the Year of the Reef lecture series. Each of these lectures had between 20 and 60 people attending. There was a long and engaging question and answer section after the public lecture.

Media Coverage: I gave formal interviews to two newspapers (SeaWeb which was then printed in the Fiji Sun, and the USP student newspaper) as well as a small island business magazine. In general the media coverage conveyed the general message, although there were some obvious difficulties in translation. This was probably exacerbated by my inexperience with media interviews.

Community: With the help of two FLMMA representatives, I presented my findings to six villages in Fiji (Vanua Levu – Navatu and Naigigi, Taveuni – Naselesele, Viti Levu - Nabukavesi, Nakorotubu and Naigani, and the Mamanucas - Solevu). In initial cases the presentation started with me doing about five minutes in English, followed by a translation into Fijian. With later presentations we found it easier for me to do the entire presentation in English followed by an extensive translation and discussion in Fijian.

In all cases the village leadership was present, and they were all extremely thankful for my presentation. In many cases they said that I was the first researcher to have come back and share their findings. Most of the villages also said that they were proud that their village had figured into my research, and I feel that this was by far the

most rewarding part of the trip. The posters turned out to be an ideal hand out, often serving as a touchstone for more engaged conversations. My only regret was that we were not able to get ones printed in Fijian for the initial round of visits.

On one trip, to Nabukavesi, I invited members from two other conservation organizations (The Coral Reef Alliance and Wildlife Conservation Society) to come join us in the presentations. They had expressed an interest in seeing what a community visit consisted of, especially after I had spoken so highly of them. I took their interest as a good sign for the future, and hope that other conservation organizations take Conservation International's lead and institute these sorts of interactions

One illustrative case of the benefit of talking with the community came from our visit to Naigigi on the island of Vanua Levu. The FLMMA representaitve Meli and I had given our presentation to a group of about 18 individuals including the majority of community leadership group. After my presentation an older gentleman said *"Dr. Josh, we have been living here by the sea for over 200 years and this is the first time we have ever heard about these things [larval connectivity] thank you for letting us know more about what is going on in our waters."*

Later on in our conversation, the same individual then asked that if conservation was so good, how could his village start setting up a protected area. I personally didn't know the methodology for a community to formally gazette a protected area, let alone integrate it into the Fijian architecture, however since I was partnered with a FLMMA representative we were able to directly parley that query into a conservation action. As of our last conversation, the rep, Meli was scheduling a community workshop meeting in Naigigi, which is the first step in formally designating a protected area.

However not all partnerships are going to be beneficial for MMAS, one in particular, the Mamanucas Environmental Society (MES), demonstrates the dangers of linking up with local community groups. The leader of the MES has a somewhat contentious relationship with the leadership of the village of Solevu. On our trip there with two junior staffers, we spent the first 20 minutes or so apologizing on behalf of the senior leadership. While the particulars were not fully explained to me, there seems to be a lack of solid communication between the MES and the Solevu villagers. I bring this up not as a direct incrimination of the MES, but rather to highlight the fact that when we partner with in-country NGOs, we not only benefit from their expertise, but we are potentially are exposed to their shortcomings, even if only by extension.

Conclusions:

Overall I found that this trip was extremely rewarding. We were able to engage a wide variety of stakeholders, from the village through the senior governmental levels. Furthermore the large number of individuals who were able to hear the talk (I estimate >350) means that we are definitely getting the word out. For future visits however, I would recommend developing some metric to evaluate the effectiveness of these presentations. I would say that Naigigi's desire to create a new conservation area demonstrates the utility of these talks, but short of that dramatic step, it is critical to set up some measure of effectiveness. My sense is that these visits are extremely useful, however in order to compensate for the expense it would be useful to have data to conduct a cost benefit analysis.