

**Effects of preferential primary consumer fishing on  
lower trophic level herbivores in the Line Islands**

**S-199  
Stanford at Sea**

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## **Abstract**

In this study we document the biomass of Parrotfish and Surgeonfish in Christmas Island, Fanning Island, and Palmyra Atoll. The three islands exhibit a gradient of fishing pressure, which results in varying levels of apex predators affecting the biomass of herbivores. At three sites with comparable conditions between the islands, we identified species' and estimated fish size in order to determine a biomass density. We also observed the feeding rates of the most common herbivore fish species at each island to establish the grazing rate. We observed very high herbivore biomass at Palmyra and correspondingly high grazing rates which bring about questions of what exactly is the connection between these herbivores and the health of the reef. This question, in turn, must be considered for future management of reefs.

## **Introduction**

Studies using archeological records have shown that subsistence fishing on coral reefs has had no impact on present fish communities (Dalzell 1998). However, today's larger scale fishing has had extremely devastating effects on these communities. Studies in Jamaica's reefs have revealed that fish biomass has been reduced by 80% mostly due to intensive fish-trapping (Monroe 1969), in addition to an almost complete disappearance of large predator species (Hughes 1994). When this disappearance of apex predators occurs in an environment, the whole ecosystem feels the effect of the removal, and can experience a trophic cascade: a process that results in inverse patterns in abundance and/or biomass and indirect effects across more than one trophic link in a food web (Pace 1999) (Figure 1). Pinnegar *et al.* (2000) found that when reef ecosystems are subject to artisanal fishing these trophic cascades not only can be found but in fact are expected. However, due to the complex interconnectedness of the food web, the effects of these cascades are unpredictable and may cause severe damage in as short a time as one to two decades (Hughes 1994). Schmitz *et al.* (2004) showed that top-down effects

triggered by predator removal can eventually lead to both a positive and a negative impact on plant resources proving the complexity of these interactions. Additionally, the alteration of plant resources would have its own bottom-up feedback on the ecosystem.

The trouble in analyzing the effect of over-fishing is that populations are often reduced to the point where “they cannot exert their former ecological role and the indirect effects of the reductions of these species are unknown because no data exists for comparison” (Dayton *et al* 1998). The only way to discover the result of an alteration to the food web is for the alteration to actually take place; however, at that point the damage has already been done and the consequences may be irreversible. In spite of these difficulties some steps have been taken toward bringing order to the complexities of the food web.

Many studies have been conducted on tropical islands with varying degrees of fishing impact putting forth several hypotheses in an attempt to shed light upon the issue. However, conflicting views arise. For instance, Dulvy *et al.* (2004) represents the most common position by arguing that the apex predator and prey populations are inversely related: removal of predators as a result of overexploitation causes an increase in their prey’s population. Hawkins and Roberts (2002) characterize one diverging opinion with the belief that this idea of a linear relationship may oversimplify the situation. Their paper “found little evidence to support...that fishing would increase the abundance of non-target species through depletion of their predators...” Their results show a more complicated scenario with the need for a multifactorial explanation. They argue that when fishing pressure is low, predators reduce their prey’s abundance, and when fishing

pressure is high, the resulting poor-quality habitat affects prey populations by keeping them low.

Due to the complex factors at play, it is necessary to identify the factors and decipher the role that each plays in the ecosystem. For example, one must consider the possibility that, given the impact of fishing, the biomass of the prey community remains constant while its population and individual fish size fluctuate. Conducting research on Christmas Island, Fanning Island and Palmyra Atoll, each of which has varying past and present levels of fishing intensity – Christmas having the greatest and Palmyra having the least—allows us to evaluate the different degrees of human impact on trophic level interactions within comparable ecosystems. The inclusion of Palmyra, an atoll that has had remarkably little anthropogenic impact, is very important due to “the shifting baseline” (Bellwood *et al* 2004). “The shifting baseline” is a scenario in which the management of tropical fisheries is implemented after exploitation has peaked, with the intention of maintaining the current state of the ecosystem. However, over time, the baseline at which the ecosystem is to be maintained shifts lower and lower. This is why the more pristine areas, like Palmyra, should be studied so that a new standard for habitat quality can be created.

Because the reef ecosystems on the islands are so complex, we had to distil their trophic interactions to the most essential. Thus, our focus was on the herbivore fish populations, their feeding, and how they are affected by the present apex predator population. Herbivorous fish may be the most important functional group in reefs. “Reduced herbivory from overfishing [of herbivores]. . . can impair the resilience of corals and prevent their recovery following acute-disturbance events like cyclones and

bleaching, leading instead to a phase shift to algal-dominated reefs” (Hughes et al 2003). Algae create a film on potential coral larvae settling sites, inhibiting recruitment. In addition, the algae forms a film on existing coral, preventing the zooxanthellae from photosynthesizing, killing it, and reducing the coral’s health – upon which the entire reef ecosystem depends. Thus, the functional group of herbivorous fish is important to understand and monitor.

What is the herbivore’s response to alterations in the ecosystem due to predator removal? A reduced apex predator population in reef ecosystems caused by over-fishing does not result in the expected biomass growth in lower trophic levels – specifically in herbivore fish species.

We considered one of four possible explanations: a) Finite levels of food resources impose a natural cap on total sustainable biomass in the ecosystem. In other words, the system has a natural maximum herbivore carrying capacity (as supported by Hunter & Price 1992). b) Total herbivore population and individual fish size are inversely correlated with apex predator density. For example, if more predators are present there will be fewer but larger herbivores as shown in Friedlander & DeMartini (2002); whereas when predators are absent, small herbivores survive and compete for the same resources as the larger herbivores, thus limiting total herbivore biomass. c) Predators eat multiple fish species, which results in an overlap of diet and compensation for the loss of a predator species by keeping herbivore numbers low. Thus as a predator is over-fished, other predators will replace its loss in ecological terms, reducing strength of the trophic cascade (as supported by Pinnegar *et al*, 2000 and Pace *et al*, 1999). d) Over-fishing is often accompanied by other anthropogenic practices that contribute to the

degradation of the reef ecosystem as a whole, which prevents the entire system from functioning properly. When this is the case, the growth of the herbivore population is also affected and is, therefore, limited (as supported by Hawkins & Roberts 2004).

## **Methods**

We made a comparison of three Line Islands – Christmas Island, Fanning Island, and Palmyra Atoll – using the fishing gradient and observing length, population density and eating habits of the dominant herbivore species as an *ad hoc* measure of the effect of overexploitation of apex predators on herbivores.

Our study proceeded with the assumption that apex predators are preferentially fished over lower trophic level fish. Accordingly, Pitcher (2001) shows that this is the case by stating that fisheries remove large long-lived or slow-growing fish – the apex predators – that are frequently replaced by those with higher turnover rates. Thus, we expected fluctuations in herbivore populations would be due to the trophic cascades and interactions within the ecosystem rather the direct effect of fishing. This said, we observed the behavior and population densities of the prevalent herbivore fish species present in the reefs around these islands, and used apex predator population densities found in our colleague's concurrent research.

We selected the two most common herbivore families – *Scaridae* and *Acanthuridae* – in the Line Islands assuming that due to their ubiquity, these species are a good indicator of the general herbivore populations and their grazing impacts. In addition we included other similar herbivore species as their inclusion proved to be necessary for an accurate interpretation of the surveyed area. We randomly surveyed 3 sites at each

island that showed comparable conditions (shallow back reef on the leeward side of the island) and conducted 6 30x4 meter transects following standard underwater visual belt transect survey methods (Brock 1954, 1982). Observing the occurrence of selected herbivore species as well as noting the size of the individual fish, we calculated biomass for each fish at each island using the allometric length-weight conversion,  $W = a SL^b$ , where  $a$  and  $b$  are constants and SL is the standard length of the fish (Fishbase). For size estimations we placed the observed fish in size ranges and used the average for the standard length. Total average biomass and biomass per size class estimates were compared among islands and sites using analysis of variance (ANOVA) with island and site nested in islands as the factors.

Furthermore, in order to determine herbivore grazing rates and its effects on the reefs, we followed the most common species found in the transects, recording approximate length and bites of algae per recorded time (2-5). Considering Belovsky's (1986 & 1997) proposal that herbivore body size is directly proportional to the amount of plant food consumed, we used the allometric scaling formula between length of fish and bite size  $M \text{ (cm}^2\text{)} = m(.001)FL^2$ , where  $m$  is a constant specific to fish species (Bruggerman 1995). We used Bruggerman's  $m$  constants  $m=4$  and  $m=5.8$  for the medium and large parrotfish respectively. For other species we conservatively estimated the bite size being half that of the medium sized parrotfish ( $m=2$ ).

## Results

We found that Palmyra Atoll has the largest parrotfish and surgeonfish biomass while Christmas Island has the least (Figure 2). Parrotfish biomass is significantly larger at Palmyra than at Christmas and Fanning (ANOVA;  $p=0.04$ ). The greatest surgeonfish

biomass was seen in Fanning and the least was seen at Christmas but this trend was not statistically significant (ANOVA;  $p > 0.05$ ). For total number of individuals observed for each species; Brown Surgeonfish, Convict Tang, Eyestripe Surgeonfish, and Bullethead Parrotfish were the four most abundant, in that order (Table 1).

In the case of Parrotfish at Palmyra, while the other size classes depict an increase in biomass, the third class size (30-50 cm) presents comparable levels to the other two islands (Figure 3). Additionally, the statistically significant increase (ANOVA;  $p = 0.009$ ) of the largest class size of parrotfish (50-75 cm) largely accounts for Palmyra's greater biomass. The smallest class size (0-10 cm) increases significantly (ANOVA;  $p = 0.0007$ ) from practically non-existent levels at Christmas and Fanning with 21 and 13 grams respectively ( $SE = 3$  and  $SE = 2$ ) to a small but noticeable average amount of 292 grams ( $SE = 10$ ) at Palmyra. The second size class (10-30 cm) for Parrotfish does not show a significant shift in biomass throughout the islands. Unlike the Parrotfish biomass, Surgeonfish biomass is greatest at Fanning (Figure 4). While the Surgeonfish first and third size classes biomass increases from Christmas to Fanning to Palmyra accordingly, the second size class biomass is largest at Fanning and it is the only size class that does not increase at Palmyra. It is actually lower than at the other two islands. We found the total herbivore feeding rate (combined parrotfish and surgeonfish) to be highest at Palmyra with 84.4% of the reef being grazed per day, while Fanning Island was 63.3% per day and Christmas Island was 42.5% per day (Figure 5). Of these totals, surgeonfish contributed the greatest percentage at all three of the islands.

## **Discussion**

Based on our results, the effect of the trophic cascade created by the assumed preferential fishing of apex predators did not significantly affect the total parrotfish and surgeonfish biomass. In fact, as the predator biomass increased from Christmas to Fanning to Palmyra, according to parallel research, (L. Katz, Unpublished Manuscript), the total herbivore biomass increased. If the hypothesized trophic cascade had taken place, the herbivore population distribution would have been altered and biomass would have been conserved. Two possible explanations arise. A weak trophic cascade may have taken place, but greater than anticipated fishing of the herbivore species at Christmas and Fanning kept the biomass low and prevented the hypothesized biomass increase due to the cascade. In this case, fishing has a greater impact on herbivore biomass than trophic cascades. A second explanation is that there is no trophic cascade and the increase in biomass is simply due to the greater habitat quality at Palmyra.

An analysis of the total biomass per size class provides support that there is a trophic cascade that affects only certain size classes. Despite the trend of increasing biomass at Palmyra, the middle-sized herbivore biomass stayed constant. It is hypothesized that this lack of change is due to the increase in apex predators that preferentially feed on the middle-sized herbivores (Katz, L., Unpublished Manuscript). The largest size class avoids predation by its size, and the smallest size class can find refuge in the reef. Accordingly, they both increase in Palmyra. The surgeonfish populations changed across the islands in a similar manner: an increase in the size classes but not the middle size class. However, in this case, the surgeonfish exhibited their maximum biomass at Fanning Island, and their biomass actually decreased in

Palmyra. Their biomass maximum could be due to greater fishing pressure on the parrotfish of Fanning island, thus opening a niche that surgeonfish could fill. The lower value of the middle size of surgeonfish on Palmyra is hypothesized to be due to the high abundance in apex predators feeding on that size class.

It is possible that overall reef habitat quality may be the most important factor affecting the biomass of herbivores rather than the indirect influences of trophic cascades. This idea is made even more noteworthy by the fact that the herbivore biomass in a reef is so closely tied to, and in many ways responsible for, the health of a reef. With the grazing rates up to 84.4% of the reef grazed per day by parrotfish and surgeonfish alone, herbivore impact on the health of the coral is probably much greater than we expected. Thus, not only do the herbivores depend on the quality of reef habitat, but the reef depends on the herbivores in order to stay healthy. These interactions are much more closely tied than thought before.

## **Conclusion**

Our results reveal the important role that herbivores can play in reef ecosystems. Our hypothesis that parrotfish and surgeonfish biomass would remain constant at all three islands did not hold. Instead, biomass increased from Christmas to Fanning to Palmyra. Despite these findings an analysis of our initial four explanations is still relevant. Our first explanation, the concept of a natural carrying capacity imposing a cap on biomass, was difficult to determine in our study, however, as we expected in our fourth explanation, the overall habitat quality, which includes food resources, was found to be paramount. The second explanation referring to the herbivore population structure

altering in response to predator pressure, proves that the effects of trophic cascades may be very subtle and their actual effects require more study to be completely understood. Our third idea of predatory compensation could not be validated within the scope of our study and would require further research.

Finally, conclusions regarding herbivores and reef management were made. Arguably, the most important functional group is that of the herbivores. Bellwood *et al* supports this idea by stating that, “A functional approach provides the basis for managing uncertainty by maintaining the functional groups that support dynamic ecological processes (for example, herbivory and provision of habitat)” (2004). Future managing should be based on functional groups. In addition, further research must be done on more pristine reefs such as those on Palmyra to provide researchers with a better idea of what the baseline natural state of reefs is. We must use this new approach and a new standard with regards to conserving the complex reef ecosystem.

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Figure 1

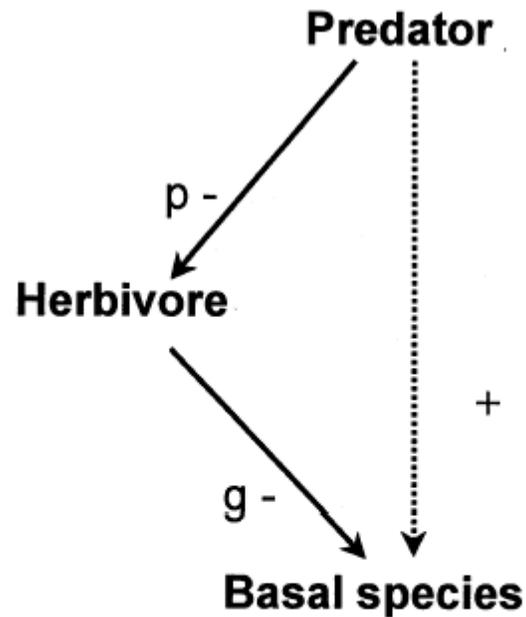


Figure 1 General diagram of a trophic cascade involving a predator which predate (p) and directly controls (-) a herbivore, the herbivore grazes (g) and directly controls a basal species. As a result, the predator has an indirect (dotted line), positive (+) effect on the basal species (after Menge 1995).

Pinnegar *et al* 2000

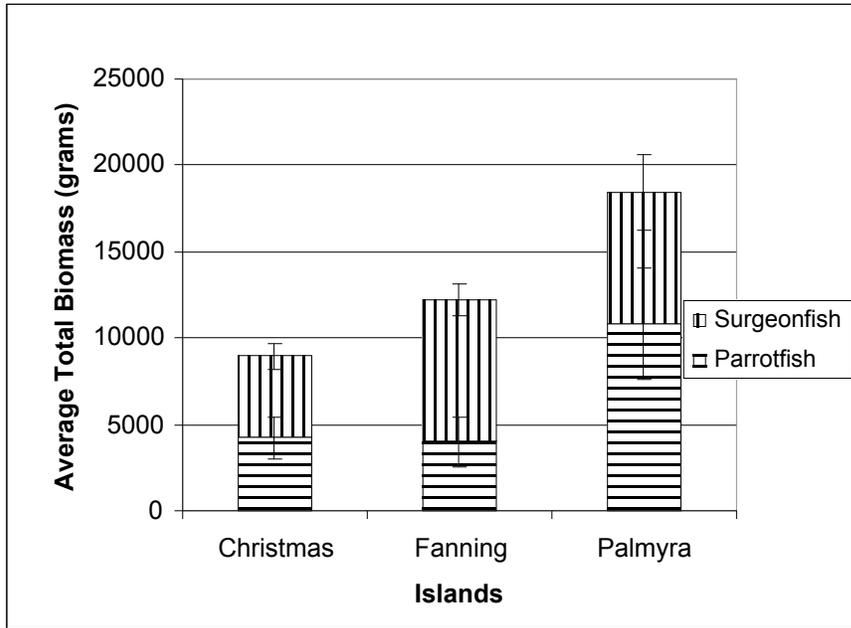


Figure 2. Herbivore Biomass in the Line Islands

|                                   | Xmas | Fanning | Palmyra | Total |
|-----------------------------------|------|---------|---------|-------|
| Brown                             | 329  | 499     | 353     | 1181  |
| Convict                           | 111  | 41      | 353     | 505   |
| Eyestripe                         | 12   | 152     | 216     | 380   |
| Bullethead                        | 45   | 55      | 214     | 314   |
| Blue-banded                       | 72   | 115     | 35      | 222   |
| Ringtail                          | 6    | 13      | 111     | 130   |
| Dark-capped                       | 22   | 15      | 48      | 85    |
| White-freckled                    | 4    | 43      | 12      | 59    |
| Longnose Tang                     | 0    | 6       | 41      | 47    |
| Bridled                           | 8    | 4       | 25      | 37    |
| Pacific Longnose                  | 3    | 21      | 6       | 30    |
| Pacific Steephead                 | 2    | 1       | 15      | 18    |
| Unidentified Striped Tang         | 0    | 10      | 0       | 10    |
| Unidentified two-toned Parrotfish | 0    | 6       | 1       | 7     |
| Roundhead                         | 3    | 1       | 2       | 6     |
| Pale-lipped                       | 1    | 5       | 0       | 6     |
| Filament Fin                      | 0    | 0       | 3       | 3     |
| Achilles Tang                     | 0    | 3       | 0       | 3     |
| Orange-spine                      | 0    | 0       | 2       | 2     |
| Tan-faced                         | 1    | 0       | 0       | 1     |

Table 1. Total herbivore abundance per island

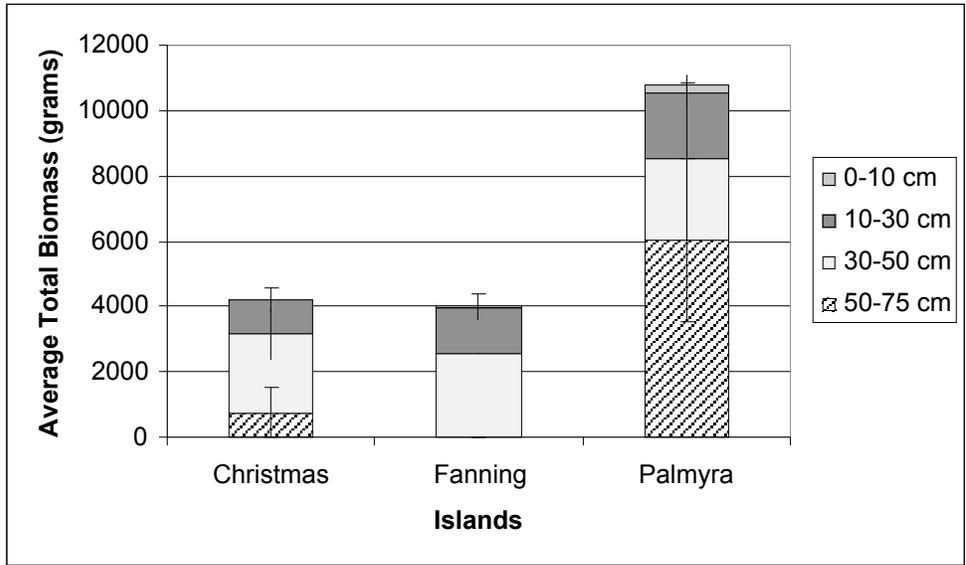


Figure 3. Parrotfish Biomass by Size Class

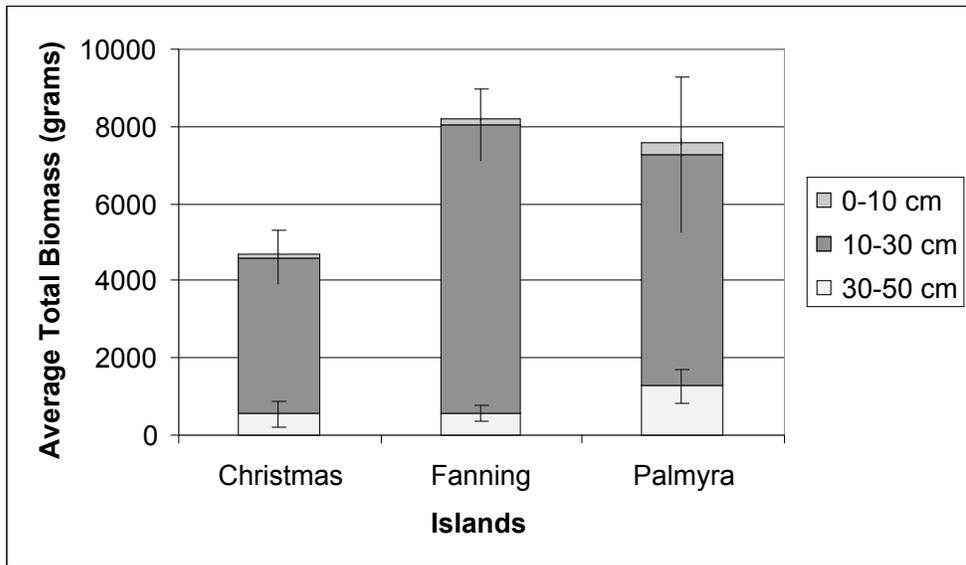
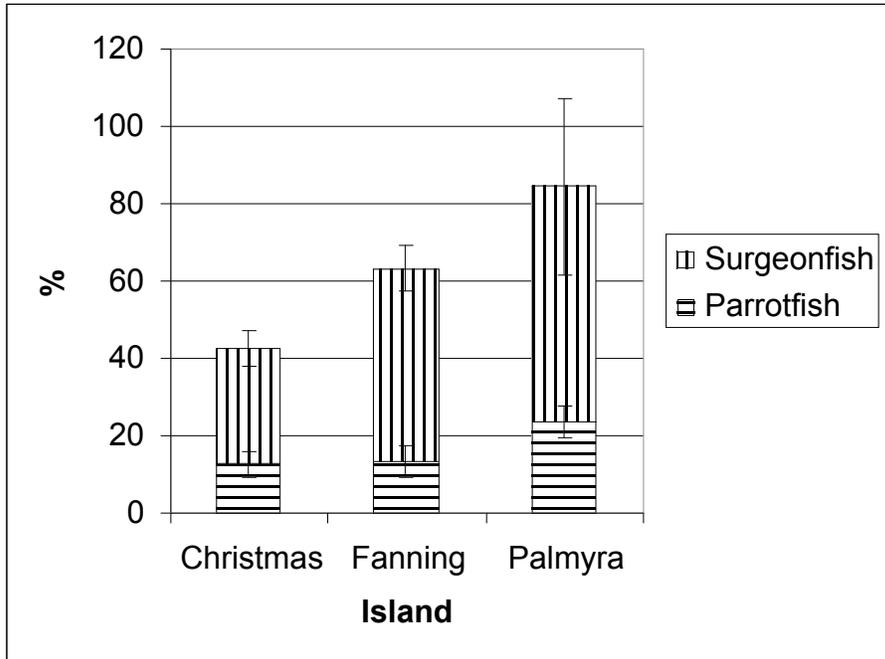


Figure 4. Surgeonfish Biomass by Size Class



**Figure 5. Daily Percentage of Reef Grazed**

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