South Kohala Conservation Action Plan

Roi Research Report

September 2013

Prepared for Hawaii's Division of Aquatic Resources, Department of Land and Natural Resources
by The Nature Conservancy, Hawaii Marine Program

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Removal Feasibility and Cost[1]

Experimental Removal Feasibility

Recolonization rate: ~1 roi every six weeks

Site Maintenance: 1 dive day every 8-12 weeks to maintain 90% reduction

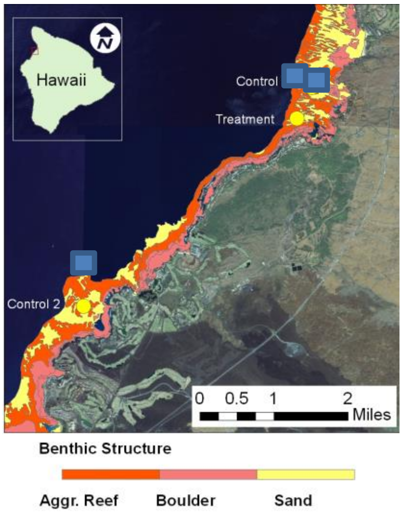
Management Cost

Reducing roi abundance in Puakō by 90% required:
2 trained SCUBA spearfishers
1 trained boat Captain
$7,158 start-up cost (gear, training, insurance)
Boat access to fishing area

Per Acre Cost:
77 personnel hours
$1,000 – 3,500 (scale dependent)

Results:

- Fish biomass decreased at all study sites two years after roi removal. *Differences were not significant by location.*
- Numerical fish abundance increased at all study sites two years after roi removal. *Differences were not significant by location.*
- Competitor abundance decreased at the reference site and increased at control and treatment locations. *Differences were not significant by location.*
- Competitor biomass decreased at the reference site and increased at control and treatment locations. *Differences were not significantly by location.*
- Small (5cm≤15cm) select prey species abundance increased at all study sites. *Differences were not significant by location.*



Volunteer Removal

1,367 roi removed (3,049 lbs est. wt.)

>70 spearfisher participants

>50 community participants

Experimental Removal

33 roi removed

5 spearfisher participants

Volunteer free divers remove more roi from larger areas in less time for minimal cost. SCUBA spearfishers are needed to fully deplete roi in a discrete area.

There was no significant difference in total fish biomass or abundance 24 months after roi removal. More time is needed to determine if this result is definitive or merely preliminary.

Engaging fishers in research can create jobs, improve results, and strengthen management.

[1] Determined through reducing roi by 90% over 3 acres of reef w/ two contract SCUBA spearfishers and information obtained during first 2 years of a 5 year study

Introduction

In August 2011, The Nature Conservancy was selected to facilitate the South Kohala Conservation Action Plan (CAP) and successfully completed a final report outlining the process and outcomes of this planning initiative[2]. The sixth objective of the CAP was to "understand and quantify effects of specific additional threats on CAP targets by 2020." The second strategy under this objective is: "Quantify effects of mangrove, kiawe, **roi**, and tilapia on coastal and coral reef ecosystems, and identify appropriate management actions." Utilizing resources remaining in the original quote, TNC successfully applied for a no cost extension to implement a portion of this specific strategy by further evaluating the management feasibility and preliminary results of targeted removal of the introduced predatory grouper, roi, at Puakō, South Kohala. This report provides information about progress made over the course of this project, highlighting work conducted with state support between August 2012 and August 2013 by summarizing two years of research findings, removal best practices, and recommended next steps to ensure that the dynamics of roi on coral reefs in Hawai'i are sufficiently understood to evaluate priority management actions to address this potential coral reef threat at a meaningful scale.

The purpose of this report is to communicate these findings and relate them to management cost, feasibility, and effectiveness in South Kohala.

Abstract

The grouper *Cephalopholis argus* (roi) was introduced as a food fish to Hawai'i in the 1950s in response to declines in commercial catches of native fishes. However, due to the prevalence of ciguatera fish poisoning in roi, they are infrequently targeted by fishers. In the absence of fishing pressure and natural predators, roi numbers have increased dramatically in recent years on some reefs in Hawai'i. With strong support from the fishing community, manual removal has been proposed as a management option and is being implemented by fishermen at multiple sites throughout the state with varying levels of direct agency support. We worked with a community in South Kohala to remove invasive roi from sections of coral reef as part of an experiment designed to measure the effectiveness of this potential management tool within the suite of conservation actions to halt or reduce coral reef degradation in Hawai'i.

1. Executive Summary

Total Project

Introduced predators can lead to biodiversity and abundance reduction via predation or outcompeting native species for resources (Balon & Bruten 1986, Faush 1988, Ross 1991). Roi were introduced to Hawai'i from Moorea, French Polynesia, in the 1950s and 60s in order to fill

[2] Available online at http://www.hawaiicoralreefstrategy.com/PDFs/3_Priority_Sites_Kohala/skcap_final_report.pdf

a sport game fishing niche (Randall 1963). Due to the prevalence of ciguatera fish poisoning associated with roi (Dierking 2007), the intended benefits of this food-fish introduction program were not obtained. Without fishing pressure, populations of roi continued to expand, and they are now the dominant marine predator on many Hawaii's reefs (Dierking 2008).

Dierking estimated roi population size in 7.8 km^2 of reef habitat along the west coast of Hawai'i at 56,290 individuals with an annual prey consumption of 93.7 t (tons) of fish and 5.5 t of crustaceans (2007). This large-scale consumption rate indicates that roi may play a prominent role in shaping native reef fish communities in Hawai'i (Randall & Brock 1960; Randall 1963; Parrish et al. 1985; Webster 2002). This research has been cited by fishermen in Hawai'i, who would like to see roi eradicated. Aquarium industry fishers are concerned that roi may reduce numbers of valuable catch (West Hawai'i Fisheries Council, 2011). However, other research suggests that Hawaiian reef fish populations exhibit an apparent resilience to the predation pressure of roi.

Based on data from long-term reef fish monitoring conducted by the Hawai'i Division of Aquatic Resources (HDAR), Walsh (Kona IEA 2011) suggested that abundance of roi is not negatively correlated to aquarium species of concern or total reef fish abundance. While species of concern in the aquarium fishery, as well as resource food fish show significant declines over time, analysis of monitoring data have demonstrated that there are no significant relationships between roi density and the density of each population parameter examined, including the density of total reef fish populations, small fish species, or piscivores in West Hawai'i (Walsh, Kona IEA 2011). Furthermore, the population size of the two most heavily collected aquarium species (*Zebrasoma flavescens* and *Ctenochaetus strigosus*) is not significantly correlated to the population size of roi (Walsh, Kona IEA, 2011). Finally, trends in roi populations indicate a 50% decrease since the peak year (2004). This decline is likely due to a die-off in summer of 2006 (Walsh Kona IEA 2011). These relationships and trends have been used as the basis for prioritization of other management actions (e.g. prohibitions on SCUBA spearfishing and additional restrictions of aquarium fish collecting), however, the success or failure of these initiatives may be influenced by whether or not they are supported by the fishing community who view roi as a threat.

This project was designed to bridge the gap between fishermen, researchers, and managers that has formed around the grassroots desire to manage roi and limited government capacity to do so. Each group has the same goal – more resource fish on Hawai'i's coral reefs. By working together on this project, acceptance of grassroots roi management grew at the government level and grassroots support to go beyond roi and work on other actions to increase fish abundance is manifesting itself statewide.

During the first two years of this five year project, we worked with over seventy local spearfishermen who removed 1,367 roi with an estimated weight of 3,049[3] lbs from Hawai`i Island coral reefs. Over half of these fish (693) were caught in Puakō, south Kohala in

[3] Based on an average weight of 789.27g/roi derived from a subset of roi (n=320) from Kona, Puakō, and Hilo.

conjunction with a scientific experiment designed to determine answers to the following important management questions:

1. **What is the cost of roi removal?**
2. **Is roi removal by spearfishing an effective management strategy?**
3. **What is the impact of roi on native reef fish communities?**

We approached these questions directly through a scientific study begun in 2010 through a partnership with the University of Hawai`i (UH) and University of Hawai`i at Hilo (UHH) under an award from the Hawai`i Coral Reef Initiative (HCRI), which funded the design of the scientific experiment and portions of the baseline surveys. With support from NOAA's Community Restoration Program, we also worked closely with the spearfishing community and local community groups to maximize participation in both research activities and opportunistic removal events in order to improve our methodological effectiveness and communicate results regularly to those most interested in our findings.

We rigorously evaluated our success through three monitoring methods, completing 274 twenty-five meter transects (Supporting Materials #1) over six survey rounds at three sites near Puakō, South Kohala (average area surveyed/round: 1.41 acres); conducting 80 one kilometer roi census tows over four survey rounds inclusive of treatment and control sites (average area surveyed/round: 24.7 acres); and recording biometric and spatial data for each roi dispatched in the 3-acre treatment area to support a fish-down analysis in partnership with Alan Friedlander at the Hawai`i Cooperative Fisheries Research Unit (HCFRU).

We also collected biometric data for several hundred roi caught at community events on an opportunistic basis including total length, standard length, height, mouth gape, weight, gut contents, liver weight, gonad weight, and gender if discernible. This information was not analyzed in conjunction with this study but is supporting other research underway in Hawai`i.

Finally, we collected ciguatera samples from most of the roi caught in Puakō, Hilo, Kona, and Kawaihae in conjunction with this project and relied on the analytical laboratory of Dr. Paul Bienfang at the UH to determine presence of measurable levels of ciguatoxin (Supplemental Materials #4). Unfortunately, this lab was unable to process samples caught after December 2011, so there are no updates to the ciguatera data obtained in 2010-11.

Seventeen project presentations were made over the first year of the project (August 2010-August 2011), including two at international conferences. During the second year (September 2011 – September 2012) eleven project presentations were made including one at an international conference in Cairns Australia and six at community outreach events. Further work included bi-annual monitoring of reef fish communities and continued collaboration and strengthened partnerships with managers, scientists, and community members through education and outreach.

During the course of this project, we capitalized on opportunities to engage the research and fishing community contributing to a measurable reduction in invasive fish, an increase in the number of people involved in invasive species removal activities, and a candid evaluation of the feasibility of invasive fish management as a restoration activity.

September 2012-August 2013

The previous section shares information over the entire project, some of which pre-dates funding to implement South Kohala Conservation Action Plan Strategies. This section will share specific actions undertaken during the eleven month CAP extension.

Monitoring: Ninety-three 25m belt transects were conducted at fixed transect locations on the Puakō treatment and control reefs to document fish and mobile invertebrate populations 18 and 24 months post-removal. Two thousand three hundred twenty-five benthic photos were taken for future analysis to evaluate coral cover and diversity. Eight scientific divers participated in this monitoring effort which consisted of a two full survey rounds in November, 2012 and May, 2013.

Catch Data: Since September, 452 roi weighing approximately 786 lbs have been removed from the Kona - Kohala coast by divers supported through this project, primarily during two community events hosted at Paniau, Puakō, and the Puakō Boat Ramp at Puakō Bay on June 29th and 30th, 2013. Two hundred twenty-nine of these roi (approx. 398 lbs) were caught in s. Kohala by spearfishers during this period. Two recolonizing roi were observed and dispatched from Puakō's 3 acre treatment reef on February 13, 2013 to maintain the suppressed roi population (<10% of baseline) on this reef.

Community Engagement: Over forty local spearfishers were engaged in removal activities in south Kohala since September, 2012, either as active fishing participants or event supporters. Project information was shared with over 200 participants and community members through a two page fact sheet, a roi dissection activity, sampling of Puakō specimens for scientific research, and brief presentations at one tournament on Maui in November, 2012; two community events in south Kohala in June, 2013; and the Hawaiʻi Conservation Conference in July 2013.

Analysis: All data collected through May 2013 was analyzed in August. Statistical analyses were performed in Minitab 14 (2004) software. Significance of all tests were evaluated at the p=0.05 level. All statistical tests were parametric using log transformed fish count data or Asinh transformed data.

A one-way ANOVA was run on the differences in fish transect observations to assess whether changes in fish assemblage characteristics and size structure varied by location after roi removal. The impact of roi presence on reef fish assemblage structure is assessed by the difference in pairs of samples between sample periods:

$Dik = X_{iCj} - X_{iLk} = X + ŋ_i + \varepsilon_{ik}$

Where X is the mean difference between control and treatment, $ŋ_i$ is the change in the difference from before to after, and ε_{ik} is the error associated with the difference (Smith 2002).

Results through August 2013

Several important results were derived during the course of this project. As this section will show, some are definitive and others will require further evaluation. Because metrics related to experimental removal of roi are more accurately tracked than volunteer removal due to the controlled nature of these activities, this section focuses on information derived through the research experiment, with brief discussion of applicability to volunteer community activities. For the purposes of maximizing this report's functionality all results are based upon the full extent of this project, inclusive of the CAP extension, but not exclusive thereto.

There are many caveats to these results. The first involves the depth range targeted. Divers removed roi from water depths of 30-60ft. as these depths are ideal for SCUBA spearfishermen with basic open water certification but are deep enough to reduce confounding influences from other activities. The cost for deeper reef work will likely be greater as shorter dive times, longer surface intervals, more compressed air, different dive equipment and/or additional training will be required to work in deeper water. The cost of removal in shallower water may be less as dive times can be extended and/or surface intervals shortened. A second caveat is the applicability of information obtained on a single complex of Puakō patch reef to other reef habitat types (e.g. boulder, fringing reef, reef flat). We intend to test this second assumption by duplicating the fishdown experiment on a section of contiguous fringing reef in north Kona in 2013. A potentially unquantifiable factor involves the skill of fishers which may be highly variable, and which may change throughout the course of removal activities. Finally, roi density and behavior is not consistent across all geographies and depth ranges as some areas are frequently targeted by shore fishers and others are rarely or never accessed with the purpose of catching roi.

Therefore, this analysis should be considered relevant for Puakō based on the experimental methods employed and any extrapolation of results below is for discussion purposes only.

Research Question 1: What is the cost of roi removal?

Removal cost was derived through careful accounting for personnel, training, supplies, and travel. Examples of these costs include:

- *Personnel:* Hours worked by divers and boat captains
- *Training:* CPR, First Aid, Oxygen administration, Dive Insurance
- *Supplies:* Dive gear, tank fills, fishing equipment
- *Travel:* Boat fuel

The following information is based upon actual costs for West Hawaiʻi for professional dive teams with valid SCUBA certification. Dive teams were supported by trained TNC staff licensed as boat Captains under TNC protocols, but it is possible for dive teams to operate independently of support staff. While it is preferred to have a third staff on hand to maximize safety, the cost of this third person may be highly variable, is not technically necessary, and is not factored into this analysis.

Non-recurring costs (Table 1) are irregular or occasional expenses such as dive gear or certifications. Recurring costs (Table 2) are daily expenses such as fuel needed to reach removal areas or wages. For the purpose of management, non-recurring costs are investments in execution of the project and must be considered up front in order to conduct field activities safely and effectively. Although they are designated non-recurring for the purpose of this report, they do recur periodically. For instance, Divers Alert Network (DAN) insurance must be renewed annually, dive gear may need to be replaced every 3-7 years. Many dive programs have their own thresholds and benchmarks for gear servicing and replacement, however, the costs included in this report are so designated because daily costs and periodically occurring costs must be considered separately in a budget analysis. Recurring costs, due to their daily nature, will eventually dominate the budget as the scale of removal increases based on the simple equation:

$$C = C_{N} + d(C_{R})$$

Where C = project cost, C_N = total non-recurring cost, d = # of days, and C_R = total recurring cost. Assuming effort, roi density, depth, and roi behavior are constant, Days (d) can be expressed as a function of area where:

$$d = d/a \times a_t$$

Where a = a single unit area (e.g. acres) and a_t = total area cleared.

Therefore, the fixed non-recurring cost of removal becomes secondary over a large enough area of reef as recurring cost accrues linearly, and may be represented as the true cost of removal over the course of a long term concentrated effort.

Non-recurring cost was $3,579 per diver inclusive of all gear necessary to conduct diving operations as well as CPR, First Aid, Oxygen Administration training and DAN Insurance. Since two divers participated in this project, the total non-recurring cost was $7,158. This cost is independent of geographic scale.

Recurring cost was $126 per diver per day, or $252 daily for the two-diver team. Based on the Puakō removal effort, eleven days were required to reduce roi populations by 90% across 3 acres of coral reef bounded by sand channels with catch declining from a peak in catch per unit effort (CPUE) on day two of fishing activity. To calculate the cost for one acre, we divided the number of days required for removal by the number of acres to derive the value of 3.67 dive days/acre.

Table 1. Non-recurring costs to remove roi for one diver based on actual cost incurred in w. Hawai‘i.

Description	Item	Cost
Free Diving Gear	Mask	$89
	Snorkel	$27
	Fins	$130
	Pole Spear	$125
	Spear Gun	$219
	Wetsuit	$260
	Weight Belt	$24
	Weights	$15
	Gloves	$20
	Float	$180
	Line	$115
	Knife	$70
SCUBA Gear	BCD	$476
	Regulator	$225
	Computer	$160
Training/Insurance	CPR/First Aid	$50
	Oxygen Admin	$50
	Divers Alert Network	$70
Total Non-recurring Costs		**$3579**

Table 2. Recurring daily costs to remove roi for one diver based on actual cost incurred in w. Hawai‘i.

Item	Cost
Personnel	$91
Tanks	$30
Fuel	$5
Total daily costs	**$126**

Dive days consisted of three 1 hr. dives by two person buddy teams. Inclusive of surface intervals, a ½ hour lunch break, and processing of fish to contribute to ciguatera and age/growth studies, each dive day was approximately 7 hours (actual dive times ranged from 37 min to 56 min, and number of dives ranged from 1-3 per day). Based on a wage of $13.00 per hour for fishing, each dive day cost $91/diver, or $182/dive team in personnel time. It is possible to increase diving efficiency by conducting more dives/day, and impact might be increased by multiple teams working simultaneously, although this would require greater dive capacity, increasing cost.

Applying the days required to clear one acre to the daily cost of removal yields the recurring cost value of $924/acre for a single dive team to effectively remove 90% of roi from an acre of reef habitat.

Total Removal Cost is best represented as a range of values as a function of area to consider economies of scale. For instance, to remove 90% of roi from a single acre, $8,082 is required ($7,158 + $924). To remove 90% of roi from three acres, as we did, $9,930 is the total cost [$7,158 + ($924*3)], and the cost per acre becomes $3,310.

With the caveats outlined previously regarding the risks of extrapolating data obtained in Puakō to other areas, expanding this to evaluate the economy of scale remains illustrative of the relative importance of the two cost types described. To remove 90% of roi from the .14 km^2 (34.6 acres) Waialea Bay Marine Life Conservation District (MLCD) in south Kohala, requires a calculated cost of $39,128, or $1,131/acre. To remove 90% of roi from all of the MLCD's on Hawai'i Island (3.24 km^2 or 800.6 acres) yields a calculated cost of $747,136, or $933/acre. This is merely illustrative, as much of Waialea Bay MLCD's benthic habitat is sand, which is unlikely to harbor roi, while other MLCD's feature greater depth ranges or different habitat types.. However, based on this extrapolation, one may observe that the total removal cost approaches the recurring cost as acreage increases, so we estimate the removal cost as a range of $1,000-$3,500 per acre to capture a likely range for future removal areas.

Table 3: Calculated theoretical removal cost based on hypothetical management scenarios

Scenario	Acres	Cost	Days	Cost/Acre
1 acre plot	1	$ 8,082	3.67	$ 8,082
Puakō Treatment Reef	3	$ 9,930	11.00	$ 3,310
Waialea Bay MLCD	34.6	$ 39,128	126.87	$ 1,131
Hawai'i Island MLCDs	800.6	$ 746,912	2935.54	$ 933

This cost is not trivial, neither is it prohibitive. Compared to terrestrial invasive species management costs for introduced animals (which may consist of one or more of the following: hiring trained hunters, using helicopters and GPS tracking units, training and dog care, fencing at $20-25 per linear foot, and building and maintaining traps or snares) SCUBA spearfishing for invasive roi has a moderate cost per acre.

Research Question 1: What is the cost of roi removal?

Answer: $1,000-$3,500 per acre (scale dependent)

The following sections of this report will evaluate the effectiveness of removal by looking at its feasibility and impact to consider whether this moderate cost is justifiable based on results to date.

Research Question 2: Is roi removal by fishing an effective management strategy?

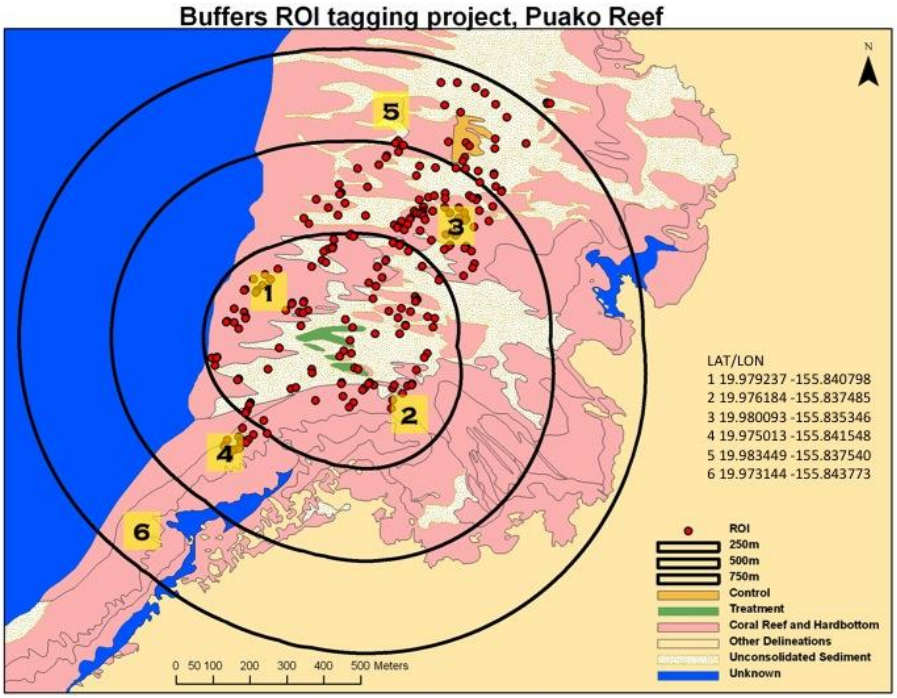
In order to answer this question we must first define appropriate measures of effectiveness against which to evaluate removal activities. Based on consultation with fisheries managers and fishers during the design phase of this experiment, a concern was raised that roi populations may be fluid enough to immediately re-colonize cleared areas. In the absence of an in situ experiment, observations of both biologists and spearfishers in w. Hawaiʻi of relatively little change in total roi abundance one or more years after targeted volunteer removal events seemed to re-affirm this expectation. Therefore, we decided to derive our measure of effectiveness from the potential for areas from which 90% of roi have been removed to be maintained, and to quantify the effort involved in doing so.

One of the ways we attempted to track immigration into the treatment reef was through a tag recapture study. Prior to removal activities, local fishers were contracted to assist with a roi tagging study. Three buffer zones of 250 m concentric rings (Figure 1) were designated with a specific tag type, color, and anatomical position on captured roi in order to facilitate underwater recognition of place of origin during subsequent underwater monitoring programs. Sixty-seven roi from the areas adjacent to the defined removal sites were captured in nets, with pole and line, and using a modified pole spear with tag applicator tip, and tagged with a standard Hallprint tagging gun and t-bar tag. Tagging events were opportunistic from February to October 2011. Movements of tagged roi into the cleared area were noted during subsequent monitoring events from June 2011 – July 2012. The geographic coordinates of tagged and recaptured roi were obtained by matching the recorded time of capture/re-sight with the logged GPS time-track. The spatial distribution of all roi tagged and re-sighted or collected were mapped in ArcGIS10.

In order to assess movements and immigration rates of roi following roi removal at the treatment reef, tagged and re-sighted/re-captured roi were mapped in ArcGIS10. Time of sight/re-capture was matched with the GPS time-track and location log in order to obtain geographic coordinates. In ArcGIS10, distances and directions of movement between roi tag and recapture locations were measured using the spatial analysis measuring tool. Time duration between roi removal and re-sight in the treatment zone was used to calculate the immigration rate of surrounding populations of roi six months after initial roi removal.

Sixty-seven roi were externally tagged in three distance buffer zones (250 m) surrounding the treatment reef (Figure 1). Six roi have been re-captured, four by community volunteers in conjunction with community removal activities and two by contract spearfishermen; six roi have been re-sighted in the survey area in twenty-four months of monitoring. Distances of roi travel averaged 94 m and generally occurred from the periphery of the removal reef towards the center (Table 4), and also in a northward direction from the northern inner buffer zone (Figure 2).

Figure 1. Map of roi tagging zones with concentric 250m buffer zones around the treatment reef. Buffer zone rings were generated in ArcGIS based on linear distance to the nearest point of the treatment reef. Red dots indicate roi observed during initial towboard census and were used to identify clusters of roi for targeted tagging. Numbers indicate which zone corresponds to the distance and direction from the treatment reef.

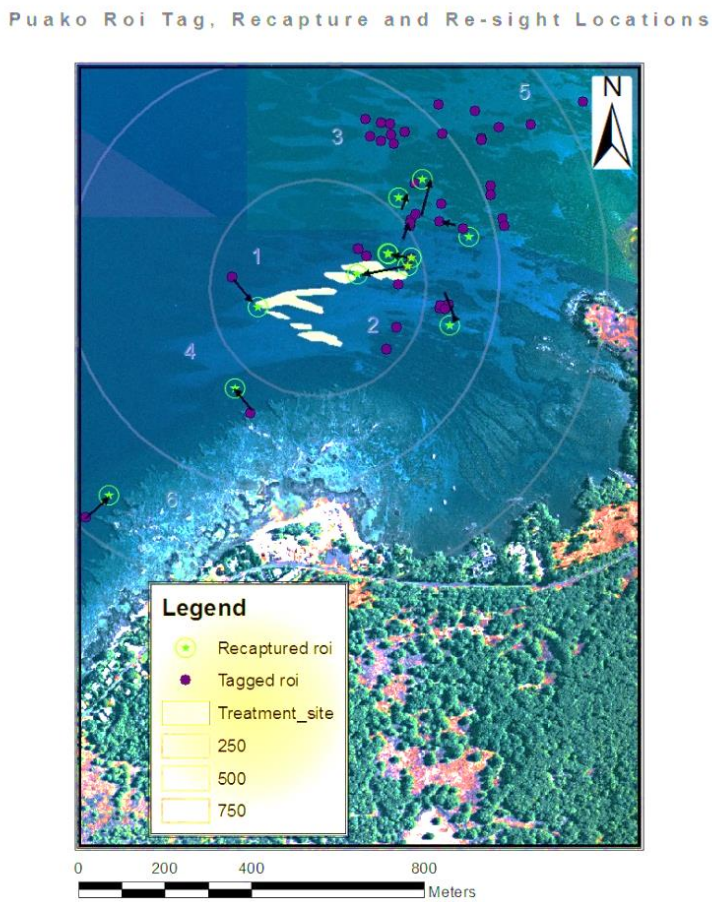


The tagging study provides useful information on the movements of roi in the vicinity of targeted removal and shows a relatively confined range of movement. Of course, the sample size is not very large, which is partly related to the difficulty of tagging large numbers of roi, and partly to the difficulty of recapturing tagged roi which may be more wary of divers than un-tagged individuals.

Table 4. Results of roi movements from tagged and resampled individuals

Obs. Method	Distance (m)
Capture (n=6)	**52**
	172
	78
	48
	67
	74
Sight (n=6)	155
	109
	85
	85
	85
	120

Figure 2. Map of roi tag and re-sight locations.



Three tagged roi and two untagged roi were observed to immigrate into the treatment reef in 6 months of monitoring after roi removal (Figure 2). During the past twelve months, two untagged roi were observed moving into the treatment reef and dispatched by divers, indicating that the rate of immigration may be variable over time based on factors beyond the experimental conditions in this study.

Over the first six months after initial removal, the recolonization rate of roi was on the order of 1 individual every 6-8 weeks. Subsequently, this rate declined to 1 roi every 8-12 weeks, leading to less frequent site maintenance. On our most recent dive on the treatment reef, a single immigrating roi was observed three months after the previous maintenance dive was conducted.

Based on this information, it is reasonable to state that re-immigration of roi to cleared areas is a gradual process. Over the course of 2 years, seven new roi were observed on the treatment reef, or 25% of the initial population removed during the 11 day fish-down in 2010. This is not surprising as previous studies (Meyer 2008) determined that roi are territorial. The slow immigration rate we observed may indicate a strong preference for existing territories among roi. Therefore, our findings indicate that roi removal by fishing is a feasible management strategy for reducing roi populations.

Research Question 2: Is roi removal by fishing an effective management strategy?

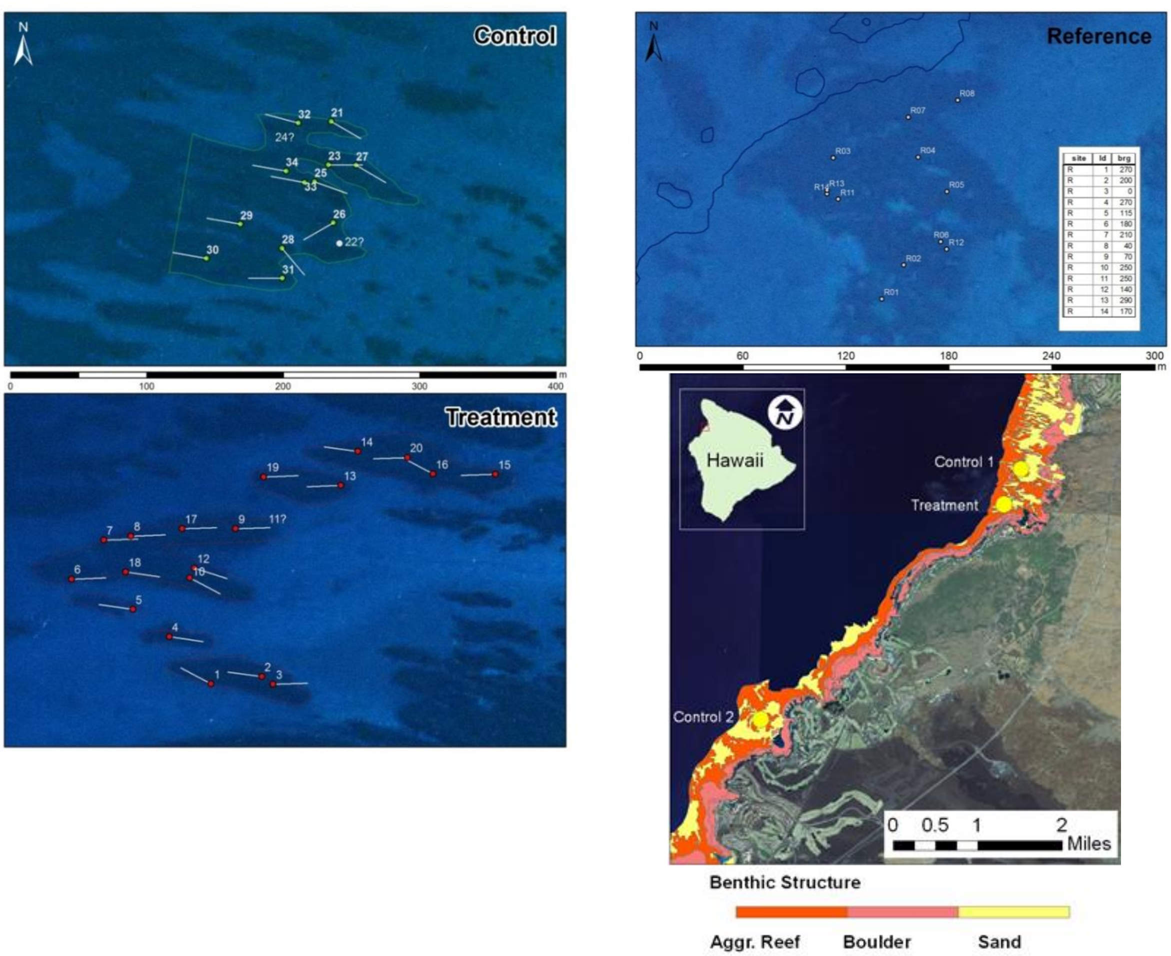
Answer: Roi removal by fishing is effective at reducing and maintaining reduced roi populations

The final section of this report will evaluate whether roi removal, which has been shown to be feasible, is an effective management tool for restoring native reef fish communities in Hawai‘i.

Research Question 3: What is the impact of roi removal on native fish communities?

A Before-After-Control-Impact experimental design was used to assess changes in reef fish assemblages associated with roi removal activities. Forty-seven permanent transects were established at randomly selected sites of similar habitat in the removal area, an adjacent control sites, and a reference site located approximately 2.5 miles to the south (Figure 3).

Figure 3. Transect locations at treatment (removal), control, and reference survey sites.



At these sites, visual fish transects were conducted following TNC Hawai'i's standard visual survey methods (Williams et al. 2009, Supplemental Materials #1), whereby two scuba divers swim in tandem along 25-m fixed replicate transect at a constant speed (*c*. 15 minutes per transect). All fishes observed within the transect were identified to the lowest possible taxon and placed in size bins (0.0-4.9 cm TL, 5.0-9.9 cm TL, 10.0-14.9 cm TL, etc.). Divers were previously trained in visual underwater size estimation techniques based on practice with various lengths of fish models that were later collected and measured.

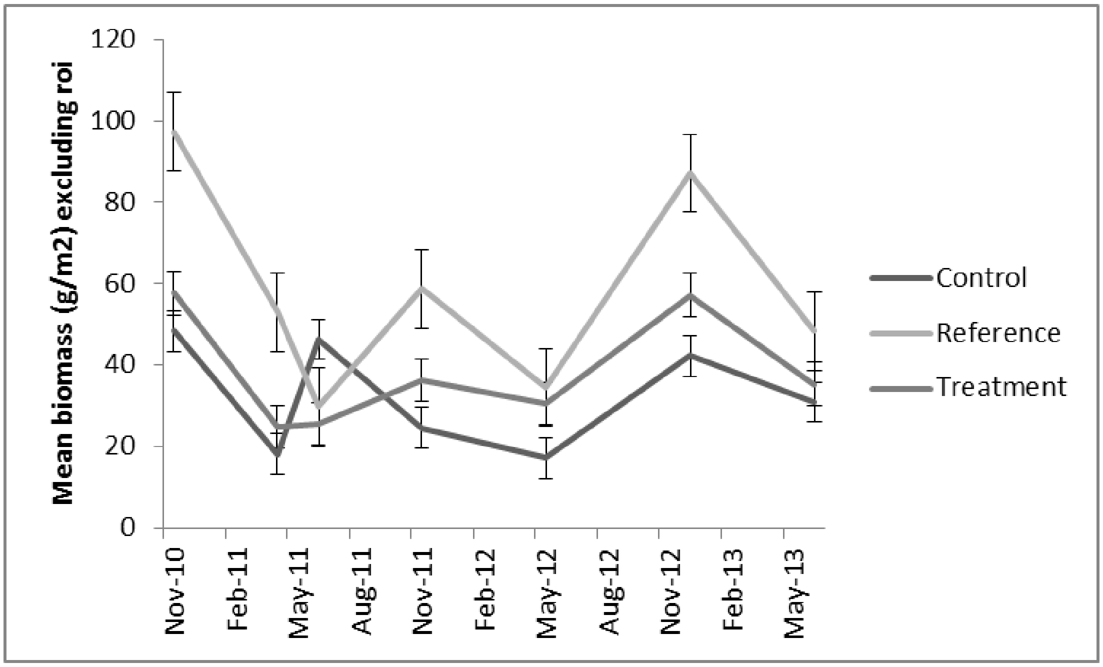
The composition of the benthic communities of these sites was quantified along the same series of permanent transects (Figure 3) in order to a) ensure that the control and reference sites have similar habitat to the removal site, and b) determine if any changes observed over time in fish communities in response to the reduction in the abundance of roi have a cascading effect on the composition of the benthos (e.g., if herbivorous fishes become more abundant in the removal zone, does the abundance of algae decrease?). Following the completion of the fish transects described above, one diver swam back along the transect line deployed, taking photographs of the bottom ever meter with an underwater camera mounted on a 0.8 m long monopod. Each photograph was then analyzed with the program Coral Point Count program with Excel extension (CPCe) developed by the National Coral Reef Institute (Kohler and Gill 2006). The second diver deployed a rugosity chain along the same transect line to measure the topographic complexity of the reef.

Two rounds of fish surveys were collected from the suite of removal and control sites during November 2010 and March/April 2011, before any roi removal was implemented in order to establish baseline conditions at these sites. Surveys were conducted again one month after roi were removed from the experimental sites in June 2011, and then have been collected semi-annually since then (November 2011; May and November 2012; and May 2013), and will continue on a semi-annual basis for the duration of the project, which is expected to conclude in 2015. Benthic data have been collected annually, starting in May 2011. With additional post-removal surveys in the coming years, temporal changes in fish and benthic communities on the individual transects will become the replication of this repeated measures BACI design.

Roi were present at all three study sites before removal, with a pooled population density of 735.7 g/ 125 m^2 and 0.61 individuals per 125 m^2. Roi occurred in 66% of the surveys conducted at the treatment site before removal and accounted for 14.3 % of the total fish biomass and 0.81% of the complete assemblage numerical density at the treatment site. The study areas for each of three study sites lie on *Porites lobata* and *Porites compressa* dominated habitat types, with total percent cover of coral at Puakō at 36.2% (SE ± 4.2) and total percent cover of turf algae at Puakō at 28.9% (Se ± 3.7%). The habitat complexity (rugosity) was found to be similar between the treatment, control and reference sites ($F_{2, 22}$ =3.2, p=0.06).

Over the seven fish survey round conducted to date (pre- and post-removal), there is considerable variability in total fish biomass both by site and by survey time (Figure 4). Across all sites, there appears to be a trend of increased biomass in fall surveys relative to spring surveys, which may reflect annual pulses of recruits to the reefs along the coastline in the summer and early fall months. If there was a strong effect of roi on the overall fish community, the expectation would be that, over time, the biomass of the treatment site would increase relative to the control and reference sites. At this time, there is no indication of such a divergence in fish biomass.

Figure 4. Trendline for total fish biomass (excluding roi) in g/m^2 at each of the three sites, with the “treatment” site being the roi removal site. Fish-down event is marked by an arrow. Error bars are one standard error of the mean.



There is a slight trend for greater total numbers of fish (excluding roi) at all study sites two years post-removal (Figure 5a). If there was a substantial negative impact of roi on fish numbers, the expectation would be that the increase at the treatment (removal) site would be greater than increases seen at the control and reference sites which still have abundant roi populations. While there is a suggestion that this may be the case (Figure 5a), there were no statistically significant differences in fish numbers from before and after removal time periods at any of the sites ($F_{2, 40} = 2.27$, $p=0.116$). Similarly, there were no significant differences in fish biomass between pre-removal and two years post-removal surveys at any of the sites ($F_{2, 40} = 0.29$, $p=0.751$; Figure 5b).

While these metrics do not show a negative effect of roi on entire fish communities, the impacts of roi may be seen first on those species that most strongly interact with roi. There are many fishes that may compete with roi for food resources (Table 5), and a higher abundance or biomass of these fishes at the roi removal site relative to the control and reference sites would suggest that roi are suppressing the populations of their competitors.

Figure 5. Total (excluding roi) fish a) abundance ($\#/m^2$), and b) biomass (g/m^2) prior to and two years after roi removal at the “Treatment” site. Error bars are one standard error of the mean.

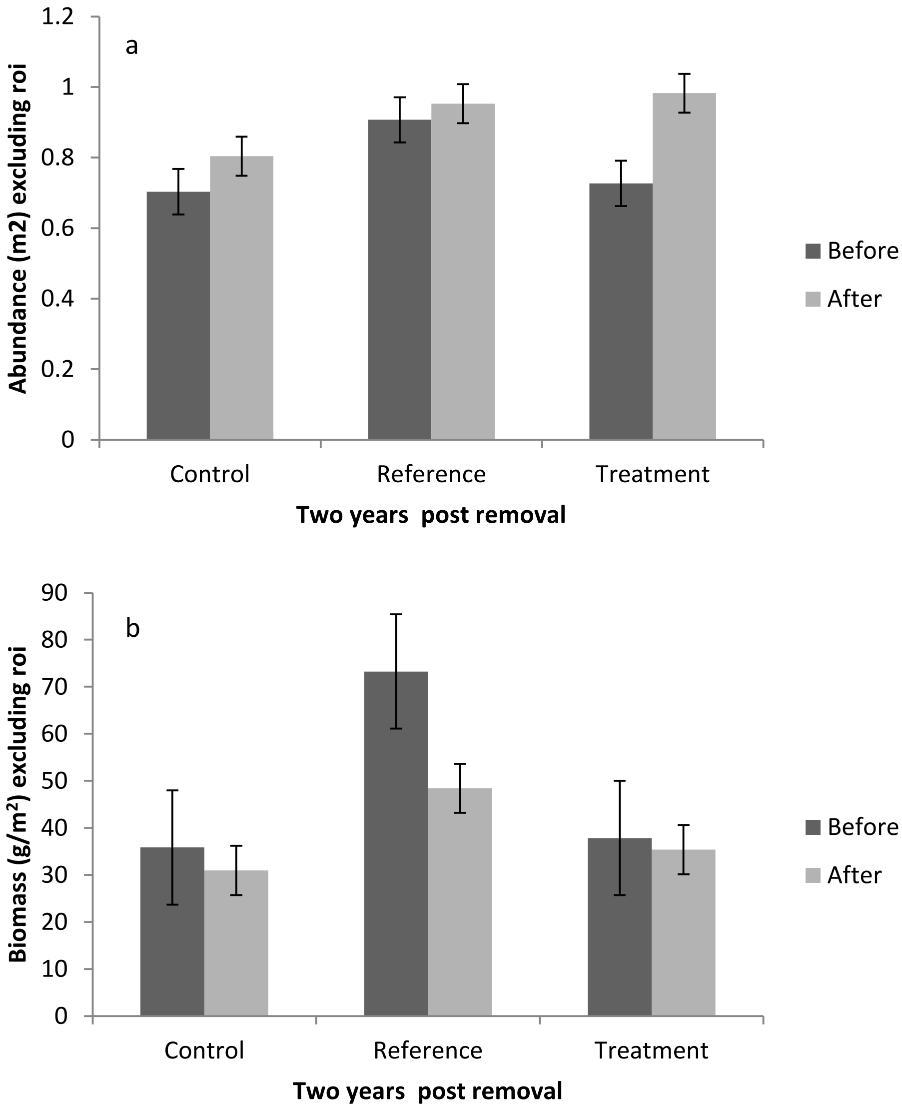
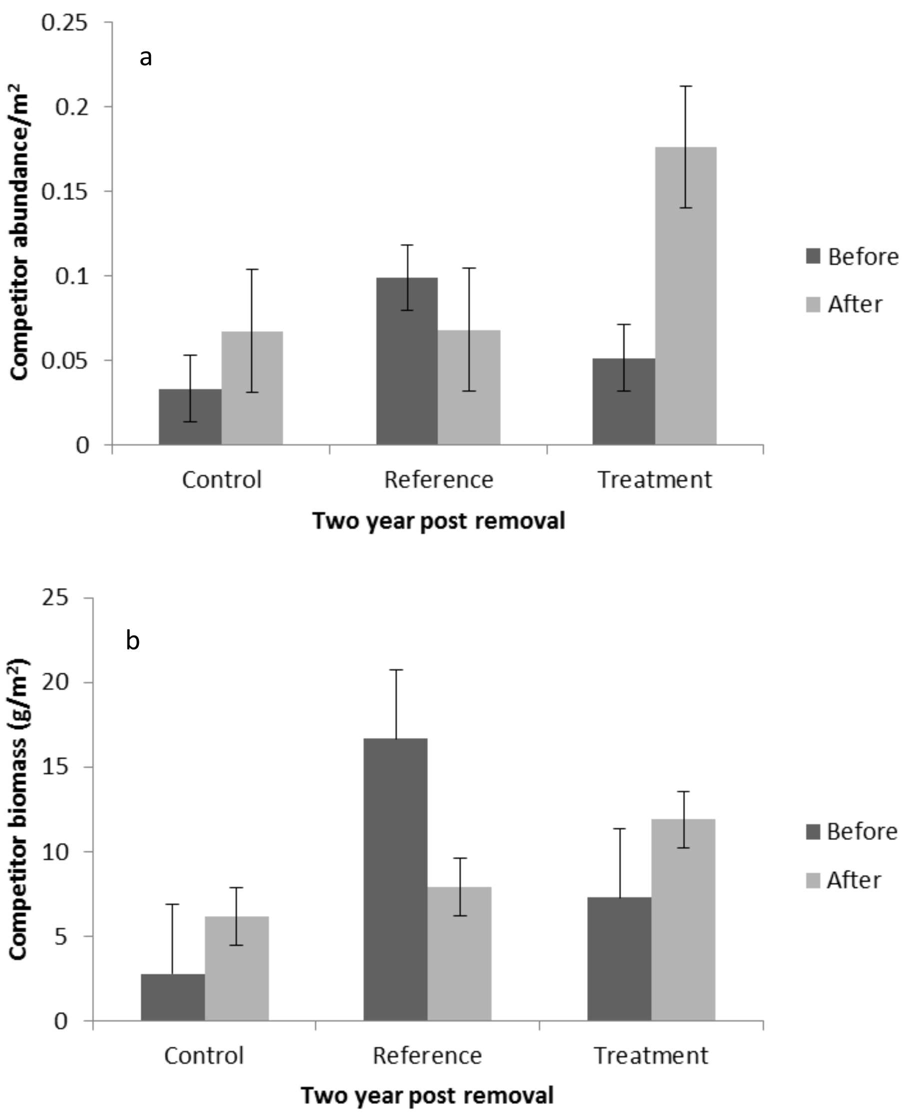


Table 5. Potential competitor species of roi in west Hawai‘i

Taxa	**Common name**
Carangidae	Jacks
Chanidae	Milkfishes
Cirrhitidae	Hawkfishes
Lethrinidae	Emperorfishes
Lutjanidae	Snappers
Mullidae	Goatfishes
Muraenidae	Eels
Scorpaenidae	Scorpionfishes
Synodontidae	Lizardfishes
Oxycheilinus unifasciatus	Ringtail wrasse

Two-years post-roi removal, the results are equivocal. Competitor abundance increased at the treatment sites as per expectation, but also increased at the control site while decreasing at the reference site (Figure 6a). Due to the high variability in the data for these fishes, none of these differences were statistically significant ($F_{2, 40}$ = 1.07, p=0.351). A similar pattern was seen with competitor biomass (Figure 6b), and these differences were also not statistically significantly ($F_{2, 40}$ = 1.07, p=0.351). While the trends in competitor abundance and biomass at the removal site are consistent with an expected response to the removal of competing roi, the concurrent increases at the control site make it impossible at this time to differentiate a response to roi removal from regional fluctuations in the abundance and biomass of these fishes.

Figure 6. Competitor fish a) abundance (#/m^2), and b) biomass (g/m^2) prior to roi removal versus two years post-removal at each of the three sites, with the “treatment” site being the roi removal site. Error bars are one standard error of the mean.



Another suite of species that would be likely to show a more immediate response to roi removal is the likely prey of roi. Previous research has identified a suite of species that roi feed on in west Hawai‘i (Table 6), particularly when these fishes are smaller in size (5cm≤15cm).

Table 6. Summary of selected prey species from Hawai‘i Island from Dierking et al. 2008

Table 3

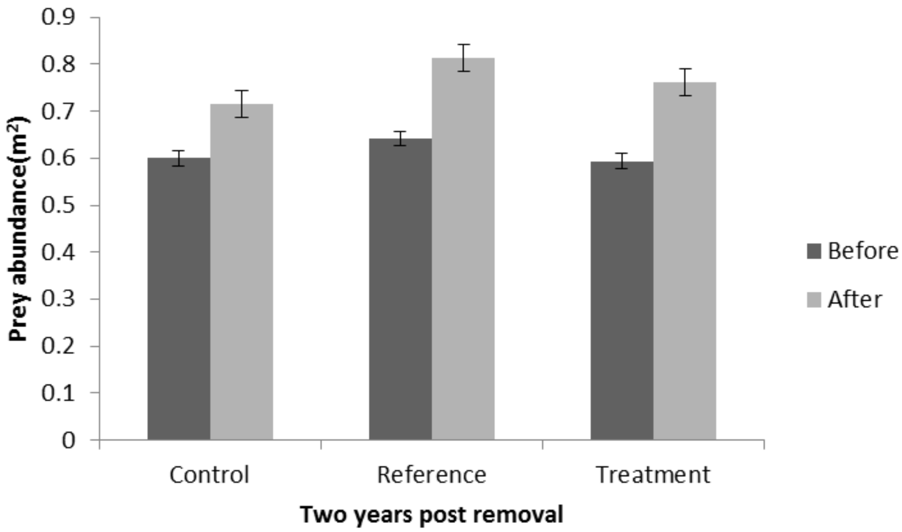
Composition of the fish portion of the diet of peacock hind (*Cephalopholis argus*) from Hawaii Island (n=179) and Oahu (n=106), based on fish prey identified to at least the family level. Crustaceans were excluded from the analysis because of their relatively minor dietary importance for *C. argus* from both islands (%*IRI* =1.9% and 3.3%, respectively). Dietary importance is indicated by percent by number (%*N*), percent by occurrence (%*O*) (calculated on the basis of full stomachs), percent by mass (%*M*), and percent index of relative importance (%*IRI*).

	Island							
	Hawaii				Oahu			
Family	%*N*	%*O*	%*M*	%*IRI*	%*N*	%*O*	%*M*	%*IRI*
Acanthuridae	16.9	9.4	13.0	20.9	8.6	5.7	11.9	7.1
Apogonidae	3.1	1.9	1.2	0.6	2.9	1.9	1.7	0.5
Aulostomidae	6.2	3.8	3.1	2.6	5.7	3.8	2.0	1.8
Balistidae	4.6	2.8	9.1	2.9	—	—	—	—
Chaetodontidae	7.7	4.7	10.1	6.2	2.9	1.9	2.1	0.6
Cirrhitidae	3.1	1.9	0.9	0.6	5.7	3.8	7.9	3.2
Holocentridae	24.6	15.1	7.5	35.8	—	—	—	—
Kuhliidae	1.5	0.9	2.5	0.3	—	—	—	—
Labridae	1.5	0.9	0.2	0.1	2.9	1.9	7.0	1.1
Monacanthidae	6.2	2.8	1.6	1.6	31.4	18.9	10.3	48.6
Mullidae	4.6	2.8	5.8	2.2	—	—	—	—
Pomacanthidae	—	—	—	—	2.9	1.9	5.0	0.9
Pomacentridae	1.5	0.9	0.9	0.2	5.7	3.8	7.3	3.0
Priacanthidae	9.2	5.7	9.2	7.7	11.4	3.8	15.2	6.2
Scaridae	9.2	5.7	34.8	18.4	17.1	11.3	19.1	25.3
Synodontidae	—	—	—	—	2.9	1.9	10.5	1.6

If predation by roi is having a strong negative impact on these prey fishes, then the removal of roi should lead to increases in prey numbers at the treatment site relative to control and reference sites. However, the results are again equivocal. Small (5cm≤15cm) select prey species abundance increased at all study sites, with no indication that this increase was greater at the treatment site ($F_{2, 40}$ = 0.31, p=0.735; Figure 6).

In summary, at this time (two years post-removal) a strong negative effect of roi on Hawai‘i coral reef fish communities has not been demonstrated. Fish communities are highly variable over time, and metrics looking at the entirety of the fish community do not as yet show any indication that roi removal has significantly altered or improved these communities. Looking specifically at those portions of the fish community most-likely affected by roi (competitors and prey), the increases in numbers and biomass of competitors and in numbers of prey are suggestive, but similar trends at the control site may indicate that these changes are simply natural variation at these sites, and not a response to roi removal.

Figure 6. Select prey species abundance (#/m^2) prior to roi removal versus two years post-removal at each of the three sites, with the "treatment" site being the roi removal site. Error bars are one standard error of the mean.



By maintaining low numbers of roi at the treatment site through 2015 and continuing to monitor changes in the fish communities at these three sites over time, we will enable longer-term responses of fish communities to roi reduction develop, and better determine if these equivocal results are the beginnings of long-term changes due to roi removal or natural changes in fish communities over time.

Research Question 3: What is the impact of roi removal on native fish communities?

Answer: Two years following roi removal, no significant effects on native fish communities has been found

Additional Findings

The purpose of this report is to support the South Kohala CAP strategy of understanding the impact of roi on native fish communities, however, we did observe other notable findings in the course of this study, with the caveat that social science metrics were not statistically evaluated and are based on observations by project team members and collaborators.

One notable finding was the potential for community participation in management to reduce conflict between fishers and managers. By engaging the fishing community in conducting this work, new livelihoods were created. Local fishers were able to fish for science and to receive compensation for their efforts. Time spent working together led to strong, lasting, mutual trust between project fishers and scientists which persists to this day. This support and trust has manifested itself in several ways including increased fisher participation in community-based management planning initiatives such as the South Kohala CAP and the Puakō Collaborative Compliance Plan. Fisher support has led to increased understanding of initiatives such as the proposed West Hawaiʻi fishing rules. After attending the contentious public hearing for this rules package, no fishers who were directly involved in this project opposed passage of rules restricting SCUBA spearfishing and prohibiting take of culturally and ecologically important species based on strong understanding of the need for new regulations to ensure a healthy fishery.

Fisher support has been reciprocated through science support for community removal initiatives which have the potential to be included as part of a phased strategy to manage roi abundance, and this support has been highlighted in local media as a successful collaboration. We also received support from NOAA's Pacific Islands Regional Office to successfully conduct scientific diver training to certify one of the local fisher participants in American Academy of Underwater Sciences (AAUS) scientific fish survey methods enabling him to join our team in the surveys conducted in May 2013, and building the local research capacity.

Management Recommendations

While more time is needed to determine the impact of roi removal on native fish communities, which will be necessary in prioritizing this action among the suite of management actions to improve or maintain the resilience of Hawaiian coral reefs, there is no observable ecological harm from supporting roi removal.

The good will generated from removal support justifies its continuation as a means of sharing information between scientists and fishers, who may not agree on everything, but who are more likely to understand one another through regular and honest contact.

Based on lessons learned through this mutually beneficial collaboration, a roi removal best practices document has been developed to inform future removal efforts (Supporting Material 2), which may be phased to maximize engagement in the early stages and efficiency once volunteer or tournament spearfisher removal has taken place. This strategy may minimize removal cost, but a phased approach has not yet been evaluated to determine if it will meaningfully decrease the time needed to fully reduce populations.

Supporting invasive species removal from south Kohala MLCD's may be a readily understandable and popular means to continue this engagement and show response to community concern about the impact of invasive species during the final years of this study. This action, should it be undertaken, will benefit the communities of Hawaiʻi Island, and will address concerns shared by members of the Waialea Bay resident community about the relative abundance of roi in Waialea MLCD. It will require support from DAR and DOCARE to permit fishing for invasive fish inside the Waialea Bay MLCD, where spearfishing is prohibited, through a special activity permit process, as well as effectiveness monitoring if resources are available.

More time is needed to definitively answer the question of roi's impacts on native fish communities, but this report's recommendation is to continue working on and supporting roi removal so that the findings of the research study can be communicated in an honest and open way, and effective communication maintained between engaged fishers and managers who will need to work together on future fisheries management strategies. This will show a response to community concern, which will be beneficial in maintaining relationships in the south Kohala region.

It would be of benefit for an analytical laboratory to revive ciguatera testing for coral reef fish so that the dynamics and progression of ciguatera can be better understood and communicated.

Acknowledgements

The Nature Conservancy would like to thank Hawaiʻi's Department of Land and Natural Resources Division of Aquatic Resources, the South Kohala Coastal Partnership, the Puakō Community Association, Roi Roundup Maui, Blue Water Hunter, the Big Island Dive Club, the Michael Morriss Memorial Fund, the Harold K.L. Castle Foundation, NOAA's Coral Reef Conservation and Community Restoration Programs, Outside Hawaiʻi, the University of Hawaiʻi's Cooperative Fisheries Research Unit, the Hawaiʻi Coral Reef Initiative, Puakō Makai Watch Program, Hokuloa Church, Kawika Auld, Rhinehart Jensen, Jake Merkel, Brian Thomas, Mike Miyashiro, Kris Kopra, Annie Mendoza, Doug Watson, Phil Hayward, Randy Clarke, Thierry Devost, Matt Ramsey, and all the other divers and community members who supported this project.

Nature Conservancy of Hawaii

Standard Operating Procedure 1: Surveys of Fish Communities Using Underwater Visual Counts

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Introduction

This standard operating procedure details the method used by The Nature Conservancy of Hawaii's marine program to survey fish populations for its 'Circuit Rider' coral reef monitoring program.

Using Underwater Visual Counts (UVC) to survey fish populations

The following survey procedures are described in this document:

- '**FHUS' transects**. 25m*5m transects. Size-class, number, and species of all fishes recorded. Duration per transect standardized to 15 minutes.

- **Timed Swims ('Resource Fish' survey)**. Fixed duration (5 or 10 minute) timed swims, focusing principally on medium-large individuals of recreationally and commercially targeted coral reef fish species. Survey divers count target species within 5m-wide belts. Distance covered per surveys measured by use of tracking GPS on surface float so that survey counts can be converted to density estimates.

These are variants of survey methods which are already widely used in Hawaii: the 'FHUS' approach is used by Alan Friedlander and colleagues for their Fish Habitat Utilization Study; and timed swims are one of the main approaches used by Hawaii Division of Aquatic Resources (DAR). Hence, data generated by TNC's circuit rider programs will be directly comparable with data from a wide range of locations spread throughout the Hawaiian Islands.

Core monitoring will be based around FHUS transects, haphazardly located within target habitat and depth strata at locations of interest. When appropriate, timed-swims will be used to supplement data on the mobile and skittish species which are not always well covered by small transect surveys. In addition, timed swims are likely more suitable for volunteer surveys, and therefore circuit rider timed swims will give the opportunity to compare parallel professional and volunteer survey programs.

Because fish counts are likely to be severely affected in very low visibility, survey should only be conducted when horizontal underwater visibility at the survey site is 20ft or more.

Equipment

For transect surveys, core equipment requirements are

- Some means of locating transect start points, presumably a GPS, together with a Pelican® float.
- Transect line(s) marked in a way that makes it possible to identify start and end points of the 25m transect (e.g. by means of white tape wrapped around the transect line). Cave reels with low stretch neutral gray line (e.g. Dacron 500 longline) have proven extremely useful.
- Compass to track bearing to endpoint of transect.

For Timed Swim (‘Resource Fish’) Surveys

- Some means of locating start and point of surveys: either a tracking GPS in a waterproof cover on a surface float, or a GPS and 2 Pelican floats to mark survey start and end.
- Watches with countdown timer plus audible alarm.

All surveys require slates, pre-printed underwater paper and pencils.

Field Sampling

A constraint of any survey method suitable for TNC circuit rider monitoring is that dive buddies are always within visual range and close enough that they can readily attract the attention of their buddy, who in turn can reach them rapidly if necessary. For that reason, fish surveys are designed on assumption that methods be appropriate for divers working in pairs.

FHUS-transect surveys

<u>Overview and Objectives</u>: Diver-observers conduct surveys on 25m*5m transects, recording numbers, species and size class (TL in 5cm slots) of all fishes encountered within transect belts as the diver moves very slowly along the belt. All species of fishes are recorded. Survey duration standardized to 15 minutes per transect (very slow) for three reasons: (i) so that survey effort is common on all transects at all locations; (ii) because skittish fishes are more likely to approach very slow moving divers; and (iii) because taking 15 minutes per survey, and counting all fishes that cross the transect ahead of the diver within that period, maximizes the possibility of encountering large, mobile species which are often rare and/or heavily targeted (and therefore of great interest to survey programs, but generally difficult to count).

<u>Detail:</u>
Start points should be located haphazardly, or, if possible, randomly, by, for example, dropping a Pelican float from a boat and using the location where the float weight settles as the transect starting point. Survey should be conducted along the depth isobar of the marked starting point, along a pre-agreed direction (e.g. if the shorelines and reef front runs broadly north-south, then divers might agree to always head along the northward depth isobar).

Prior to beginning surveys, the target depth range and habitat type must have been defined for that location. Those may vary among locations, but default target is 10-50ft deep hard-bottom.. If the transect start point marked by the float would not allow more than 70% of the transect to fall within the target habitat and depth, then, if possible, the start point should be haphazardly manually relocated into a suitable position within 10m of the original start point.

Diver prepares for survey by attaching the transect line to the reef bottom, and then mentally fixing the direction of swim, the belt width (5m), and the actual starting point of the transect (e.g. position of the start marking on the transect line). When ready to begin the survey, the diver record the depth and survey start time, and then begin to swim very slowly along the transect while holding the recording slate and the transect reel in one hand and slowly paying out line as they move forward. All fishes ahead of the diver and within or moving across the transect belt should be recorded. This method therefore entails the diver alternating between looking ahead to catch mobile mid-water fishes, and more careful scrutiny of the bottom to record reef-associated and cryptic species. To the extent possible, divers should keep track of whether particular fishes have already been recorded, so that fishes which reenter the transect belt later in the survey are not double counted. As the diver approaches the end of the 25m transect, they should begin to estimate the end point of the survey, which can be done with practice by looking at the amount of line remaining on the reel. Divers should make a mental note of the location of fishes which are recorded close to the estimated end point, and on reaching the end of the transect should cross off those that were actually beyond the end of the transect.

At the end of the transect divers should record the time, so that total time taken for the survey can be calculated. Target time per survey is 10-15 minutes. If survey time grossly deviates from that, data should be discarded. Divers then turn around and swim back down the transect reeling up the survey line.

Divers record benthic inverts of interest on the return swim (i.e. while reeling up the transect line). Inverts are counted in a 2m-wide belt centered on the line being reeled up.

An example data sheet is on following page. Most commonly encountered species have an entry, but there are also blank spaces to write in name or code of any other species recorded. For each fish observed, size (TL) is recorded in 5cm slots: “A” = 0-5cm; “B”=5-10cm; “C”=”10-15cm; “D” = 15-20cm; “E” = 20-25cm. Size of fishes larger than 25cm are recorded to nearest 5 cm. NB, record size as ‘25’ if length is above E size, but too small to be recorded as 30 (i.e. between 25 and 27.5cm). For some species, information on the ‘variant’ or phase is also recorded. For labroid fishes (wrasse and parrotfishes), terminal phase fishes should be identified.

<u>Variant – Parallel simultaneous surveys by pair of divers:</u>

Data quality would be optimized by having single divers working completely separately. However, as mentioned above, safety considerations dictate that divers work in pairs or larger groups. One possibility, used by the FHUS program, is for one diver in a pair to conduct fish surveys, and for the second diver to follow closely behind while conducting a benthic survey on the same transect. There may be times when that is suitable for the circuit rider program, but, because fish survey data is inherently much more variable than benthic survey data, the best use of circuit rider survey time would likely be achieved by devoting more effort to fish surveys than to benthic surveys.

One means of allowing both divers to conduct fish surveys while remaining in visual range within 10m of each other, would be for a dive pair to conduct two simultaneous parallel surveys remaining approximately 10m apart. In order to make data from paired surveys comparable with data from single divers, each diver should conduct their survey as if it was an independent count (i.e. record all fishes within their transect belt irrespective of whether they are also counted by the other diver). The two transects surveyed by the dive pair would clearly not be statistically independent and hence data from the two divers would have to be pooled into a single survey value for analysis. Biomass and abundance per survey would be directly comparable between paired and single diver surveys, but because paired surveys cover twice the area of reef, total species richness and other diversity measures would not be. It would, however, be relatively easy to generate comparable richness data, e.g. by randomly selecting richness values from one of the two counts per pair when making comparisons with single diver surveys.

For paired surveys, starting locations should be determined so that at least 70% of both divers' transects fall within the target habitat and depth range. The method for locating the starting points of the two transects relative to haphazard/random start location (e.g. float weight) should be determined prior to entering the water: either one of the divers uses the marked location as the starting point and the other sets their start from location from there, or the two divers begin their surveys 5m either side of the marked location.

‘Fixed-Transect’ Surveys Data Sheet

Names: / Date: Times: / Site: Depth:		
A. nigrofuscus		*A. planci*
C. agilis		*C. gigantean*
C. vanderbilti		*D. paucispinum*
C. strigosus		*E. calamaris*
T. duperrey		*E. diadema*
Z. flavescens		*H. mammillatus*
	Hawkfishes	*T. gratilla*
Butterflyfishes	*C. fasciatus*	**Triggerfishes**
C.auriga	*P. arcatus*	*M. niger*
C. lunula	*P. forsteri*	*M. vidua*
C. multicinctus	**Parrotfishes**	*S. bursa*
C. ornatissimus	*C. carolinus*	*R. rectangulus*
C. quadrimaculatus	*C. perspicillatus*	*X. auromarginatus*
F. flavissimus	*C. spilurus*	**Wrasses**
F. longirostris	*S. psittacus*	*B. albotaeniatus*
	S. rubroviolaceus	*C. gaimard*
Damselfishes	**Box/Pufferfishes**	*G. varius*
A. abdominalis	*C.amboinensis*	*H. ornatissimus*
C. hanui	*C. jactator*	*L. pthirophagus*
C. ovalis	*O. meleagris*	*M. geoffroy*
D. albisella	**Surgeonfishes**	*O. unifasciatus*
P. imparipennis	*A. achilles*	*P. evanidus*
P. johnstonianus	*A.blochii*	*P. octotaenia*
S. marginatus	*A. dussumieri*	*P. tetrataenia*
	A. leucopareius	*S. balteata*
Filefishes	*A. nigricans*	**Others**
C. dumerilii	*A. nigroris*	*A. furca*
C. sandwichensis	*A. olivaceus*	*A. chinensis*
	A. thompsoni	*C. potteri*
Goatfishes	*A. triostegus*	*C. argus*
M. flavolineatus	*C. hawaiiensis*	*L. kasmira*
M. vanicolensis	*N. hexacanthus*	*M. grandoculis*
P. insularis	*N. lituratus*	*M. berndti*
P. cyclostomus	*N. unicornis*	*M. kuntee*
P. multifasciatus		*Z. cornutus*

25*5m FISHES (15 minutes) 25m*1m INVERTS while reeling up transect line

‘Resource Fish’ Timed Swim

Overview and Objectives:
Pairs of divers conduct fixed duration (5 minutes) timed swims recording the number of all medium-large (>15cm TL) ‘resource fishes’. Divers aim to cover moderate to large areas while looking as far ahead as possible so that diver-observers can focus on the large, mobile and sometimes skittish fishes which are the principal targets of commercial and recreational food fisheries.

Detail:
Divers work in pairs, starting from a randomly or haphazardly-located starting point. Divers swim along the depth contour in a pre-agreed direction (relative to shoreline/reef front) from the starting point and remaining where possible within a contiguous stretch of habitat. Divers should aim to move steadily, and adjust their own speeds to prevailing currents so that total distance covered is around 100 m per 5-minute surveyed. Each diver records the size and number of ‘resource fishes’ (Table 1) with total length larger than 15cm within a 5m-wide swathe centered on themselves. One diver in each pair will either tow a surface float with a tracking GPS, or deploy a buoy at the end of the swim, so that distance covered per survey can also be calculated (and therefore counts can be analyzed on a per-time or per-distance basis). Data from a pair of divers will always be pooled prior to analysis and therefore, divers should strive to not double count fishes (e.g. a fish moving across the field of vision of both divers should only be counted by one of the pair, normally the diver from which side the fish started). Fish sizes are to be recorded in the same 5cm-slot size categories as the fixed transect surveys: “D” = 15-20 cm; “E” = 20-25 cm and fishes larger than 25cm recorded to nearest 5 cm.

Additionally, the number and size of charismatic or rare resource taxa such as Jacks, Uku, Mu, O`io, Awa, Ama Ama, Barracuda, Sharks & Rays, and turtles observed at any point during the survey, but not within 5-m transects, should be recorded in the ‘off-transect’ section of the data sheet.

Table 1. ‘Resource Fishes’

Family/Grouping	Species
Carangidae	All jacks
Scaridae	All parrotfish
Labridae	All wrasse (NB few species >15cm TL) except *T. duperrey* and *G. varius* (both of which are occasionally larger than 15cm)
Acanthuridae	All surgeonfish, except *A. nigrofuscus*, *Z. flavescens* and *C. strigosus* (all too abundant) and *A. thompsoni* (too high in water column to be consistently counted using this method)
Mullidae	All goatfishes
Serranidae	*C. argus* Any other grouper
Lutjanidae	All snappers
Lethrinidae	*M. grandoculis*
Kyphosidae	*Kyphosus spp.*
Balistidae & Monacanthidae	*Balistes polylepis* *Sufflamen fraenatus* *Xanthichthys spp.* *Aluterus scriptus* *Cantherhines* spp.
Tetraodontidae & Diodontidae	*Arothron meleagris* *Diodon* spp..
Charismatic Others..	Sharks, Mackerel, Tuna, Turtles

NB Table 1 includes a few groups (e.g. some triggers and puffers) which are barely or not fished. Additionally, several fishery-target cryptic or semi-cryptic species (soldierfish, squirrelfish, big-eyes) as well as mobile upper-water column species have been deliberately excluded because adding those would undermine divers’ ability to record core species of interest. As described above, observes should aim to look ahead in the water column to maximize ability to record the majority of target fishes.

'Resource-Fish' Timed Swim Data Sheet

Names: / Bearing: Date: Site: Depth:	
>15cm (D size) only	**Start Time: Visibility:**
A. achilles	
A. blochii	
A. dussumieri	
A. guttatus	
A. furca	
A. leucopareius	
A. nigroris	
A. olivaceus	
A. virescens	
B. albotaeniatus	
C. argus	
C. carolinus	
C. gaimard	
C. melampygus	
C. spilurus	
Kyphosus sandwicensis	
Kyphosus vaigiensis	
Kyphosus sp.	
L. kasmira	
M. grandoculis	
M. flavolineatus	
M. vanicolensis	
N. brevirostris	
N. hexacanthus	
N. lituratus	
N. unicornis	
O. unifasciatus	
P. insularis	
P. cyclostomus	
P. multifasciatus	
S. dubius	
S. psittacus	
S. rubroviolaceus	
Others…	
Non-Transect Target Fish	Record number and size of any of these seen at any time throughout the survey.
# & size of all Jacks, Uku, Mu, O`io, Awa, Ama Ama, Barracuda, Sharks & Rays	

Quality Control in Fish Counts

- Prevention of double-counting of fishes in timed swims

Dive surveyors in timed swims always work as a pair and their data is always pooled to produce a single value, representing all fishes present in the transect swathe(s) observed by that pair during the survey. It is therefore important that the dive pair avoid double counting fishes which cross both observer's transects.

In the timed resource swims, because divers are not working off a fixed transect line, it is not practical for divers to survey non-overlapping but immediately adjacent transects. Instead, divers should remain approximately 10 m apart, while each separately surveys a 5 m wide swathe centered on their bodies. Given the absence of a fixed line to work off, it is recommended that one of the divers (agreed beforehand) takes responsibility for setting the direction of travel (following either a bearing or the depth contour, depending on what has been deemed appropriate for the site), with the other diver following very slightly behind and adjusting their line of survey to fit with that set by the leading diver. As transects are not immediately adjacent, it can be difficult to determine whether a fish swimming from the other observer's side has been double counted, but observers should make notes when there is uncertainty, and resolve those after the dive.

- Consistency and accuracy of fish-size estimates

Fish-size distributions are some of the best data for identifying impacts of fishing and protection. Unfortunately, there can also be large and systematic differences in size estimation among observers. Our experience of length estimation training is that divers can quickly learn to accurately estimate sizes of fish models attached to lines underwater, but that has limited impact on their actual performance in fish counts. The key to consistent and accurate size estimation seems to be for divers to maintain personal responsibility for their performance and get in the habit of regularly cross-checking and discussing size estimates with their partner after a survey. Additionally, observers should regularly check their size estimation, before or after surveys, by estimating sizes of benthic objects and then checking those estimates by physically measuring the object (for example, by using a slate marked at 5 cm intervals). Collaborative post-dive cross checking is also important when it comes to confirming or checking species identifications.

- Consistency of transect widths

Transect widths are visually estimated in all the survey approaches described here, and there is therefore scope for poor or inconsistent estimation of transect widths to negatively affect data quality. As above, this is something observers need to take personal responsibility for. One option would be to deploy a line of the appropriate size at the start of some transects to assist observers with mentally fixing the belt width. It is recommended that 5m lines are frequently or always deployed by inexperienced or in-training divers to mentally fix belt widths, and occasionally thereafter by more experienced observers.

- Training of new surveyors

Novice surveyors tend to count consistently fewer fishes of some families, particularly groups which contain some species or life-phases which are cryptic or semi-cryptic or are otherwise somewhat hidden or elusive (e.g. soldierfish, wrasse, benthic pomacentrids, and small surgeonfish). However, the difference in performance between novice and more experienced observers rapidly declines as surveyors gain experience, and is generally small to negligible by the time a surveyor has conducted around 20-50 survey dives. For generally mixed teams including observers with a range of experience levels, this isn't too serious a consideration, but survey programs should seek to avoid gross imbalances in teams' experience levels among times or places if the data is to be comparable. Furthermore, new observers should receive training, including realistic practice surveys, so that they are adequately familiar with methods and with data sheets prior to their data actually being used. One possibility would be for trainee divers to shadow more experienced surveyors for a number of survey days until their data is of acceptable quality.

- Cross checking

Routine post-survey checking of your partner's data sheet is recommended as a means of ensuring consistency among the survey team in species identification and sizing, and, as mentioned above, to reduce double counting. It is particularly important as a way of raising and/or ensuring quality of relatively new surveyors.

Supporting Materials #2: Roi Removal Best Practices

Roi Removal Best Practices for Hawaiʻi
Created September, 2012

*What this document **is*** – The purpose of this document is to provide basic removal recommendations based on two years of invasive fish removal at Puakō, Hawaiʻi. Input and observations from ten years of removal in Maui, and two decades of grouper removal research informed these recommendations. It is written in language that should be understandable to a general audience to enable better communication of roi management efforts.

*What this document **is not*** - This document is not a management plan and its goal is not eradication of invasive fish. It is not a criticism of any fishing methods not covered here nor does its author claim to be an expert at any type of fishing or on roi themselves. It is not an exhaustive review of every possible method or technique that may be successful for the purpose of catching roi – far from it. It is not a call to arms or a justification for action. It may not be factually accurate beyond a statistical doubt. Basic issues of safety, access, and legal liability are not covered here and are not assumed by the writer.

Background – The predatory grouper roi (*Cephalopholis argus*) was introduced to the Main Hawaiian Islands (MHI) from Moorea in 1956 and 1961 in order to augment declining reef fish stocks. Since roi's introduction, it has spread to all of the MHI, becoming the dominant predator on some Hawaiʻi coral reefs. Grassroots efforts have been underway to remove roi from reefs since the 1990's. Research into the effect of roi has contributed information to managers since 2000. Since 2011, roi populations have been reduced by >90% on 3 acres of coral reef in Puakō.

Pre-removal Recommendations

1. **Community consultation:** Not every community is worried about roi; in many places in Hawaiʻi they are still eaten. In fact, there is a commercial market for the species in Oahu. Even if a community or group is concerned about roi, it may not be their highest priority, and they may not be willing to support intensive fishing pressure. On the other hand, they may be completely supportive but need to share information about sensitive areas, facilities, access sites, etc. to ensure activities don't do any unintended damage to resources. A vital first step is taking time to understand the dynamics of any place where removal is proposed and working with the community in the area to clearly communicate goals and objectives of removal, as well as listen to concerns and suggestions. It's also important to know if any fishing rules apply if fishing in a management area, and if so, what additional steps are necessary to apply for special permits.
2. **Habitat assessment:** Roi have certain habitat preferences that are well known to fishermen. They prefer finger coral dominated reefs with holes and relief. They will also utilize wall habitat, cracks,

and crevasses. Juveniles are said to be found in shallow tidepools. They are not likely to spend much time over sand. They can be found from the water's edge to at least the edge of the fringing reef (60-120 feet). It is important to have a map of the focal area for removal and even better to scout the area several times prior to removal to identify hot spots where harems of roi are found. Benthic habitat maps can be helpful when looking at new areas for the first time.
Note: *Conditions matter* – when the water is clear, roi can be found easily moving across the reef or resting atop coral. During cloudy conditions, it is rare to see as many roi in the open, but they may still be found inside holes, cracks, and crevices.

3. **Dive Planning**: Based on the habitat assessment, you should have a general understanding of how deep the habitat goes and how many roi it's likely to host. You'll need to use this to decide how to dive the area including how many and what size spear to use; whether or not free diving is viable; or whether or not a vessel is needed to reach the area. It is also helpful to divide larger areas into manageable sections. For instance, if there are a number of patch reefs in the area, focusing on one or two at a time will enable more effective total reduction than swimming quickly between all reefs. These decisions will directly influence how successful you are. Remember, you never get a second chance to see a roi for the first time, so you have to be prepared. Now is also the time to evaluate the needed capacity for removal. Is it an afternoon for two people or a full time job for ten?
4. **Equipment**: The last step in pre-removal planning is securing the appropriate equipment for your activities. Most divers already have some or all of the gear needed to conduct removal, but, if someone was starting from scratch, they might consider the *removal gear* list a good starting point. Regarding spears, a long (>9ft) pole spear is the preferred tool for free divers on finger coral reefs. A shorter spear may be needed to maneuver near ledges or caves and a gun may help to dispatch wary roi that will not allow divers to approach. In any case, it makes sense to talk to the folks at the fishing store (e.g. S. Tokunaga Store in Hilo) about what specific gear is most effective and appropriate for the area and dive plan, and pick up some tips and tricks for fishing at the same time.

Removal Recommendations

Recommended Method:

Spearfishing. If you have heard that roi will readily take bait on a hook and line, so have I, and from many otherwise normal people. We've worked with some of those people to try and recreate the conditions under which roi attacked their gear, but have never been successful in doing so. In our experience over weeks of fishing at different tides and moon phases, using live bait, jigs, squid, shrimp, fresh he`e leg, spoons, flashers, and worms, we never experienced a feeding frenzy of roi, and can confirm that spears are the most effective method we've tried.

Recommended Timeline:

Step 1: *Skilled* Volunteer Fishing: An interesting observation about roi is that they are generally curious and approachable until they have been shot at, cursed at, forced deep into the reef, and shot at again. The difference between catching a fish in five minutes and five days may be directly related to how it is approached in the first five seconds. A truism of roi fishing is that *It's better not* *to take a shot that to take a shot and miss*. There are limits to this truth – each roi has a comfort zone and if a diver encroaches on that zone, it will hide, but difference in a spooked roi and a missed roi is this: generally a spooked roi will come out again, but a missed roi will find a good hole and stay in it for a really long time. More about roi behavior in the final section.

In many cases, volunteers will work for free because they enjoy what they do, but it is always recommended to provide something to share gratitude for their help, especially if it is part of a removal plan you are conducting. Food is always a safe bet and providing breakfast, lunch, and/or dinner for divers shows that their contribution has not gone unnoticed. Unofficial prizes, gifts, and tokens of gratitude are also a good idea when practical.

Step 2: *Skilled* Professional Fishing: Skilled volunteers will be able to catch a lot of roi in a short period of time. They will also make the remaining roi more wary of free divers. Therefore, it is recommended that, once volunteers are unwilling or unable to continue removal, professional removal commence. Why, you may ask, would volunteers become unwilling or unable to continue? Volunteers are not compensated, and therefore will have only limited time to devote to fishing. Because of that, enjoyment of fishing activities is a strong predictor of volunteer motivation. Once roi are extremely difficult to approach or catch in abundance, volunteers will likely move to other areas.

Professionals, on the other hand, will be able to justify spending a lot of time to catch a few fish. Because they are compensated, they can spend an entire dive, day, or week focused on a specific area or fish in order to maximize population reduction. One dive team should be sufficient to remove >90% of roi from one acre in 5-7 days. It may not be possible to catch 100% of roi in an area through spearfishing, but this assumption could be tested by a trained and effective team in a new area.

The more skilled the professional fisher, the less time will be needed to clear an area. It is even more imperative that they be accurate shooters and efficient stalkers to dispatch the wary roi that remain after the volunteer blitz.

Note: Professional fishers are capable of clearing an area start to finish, and are generally happy to do so. There is a social trade-off to doing this that comes in the form of less buy-in for removal activity, so it is recommended to engage lots of people in the beginning and have a small team come in to finish the job.

Step 3: Site Maintenance: This step can be done by volunteers, professionals, or managers depending upon capacity. Over the 12 month period of the study, new roi colonized the reef at the rate of one ever 1-2 months, so diver effort could track on a similar pattern. There were two roi that were never able to be removed, and which were observed on some of these dives. Divers will get to know the survivors very well, and will see where they run to at the first site or sound of people in the water. There are proven methods of catching fish inside of holes in the reef, but these methods do not only kill roi, and were deemed more harm than good for the removal study.

One must always weight the benefit and the risk to native species in determining how far to proceed with roi removal.

Roi Behavior

Harems: Roi live in territorial groups with a dominant male and several females. Each day these groups will move around within their territory. The largest roi in a group is usually the male.

Spawning: Mating may occur seasonally at dawn and dusk. Ripe gonads have been observed in May-early June, and the possibility of a second spawning each year has not been evaluated. Roi do not aggregate in large numbers to spawn.

Cooperation: Roi will hunt with moray eels and may follow small jacks around the reef. They may sometimes sit motionless if they detect an octopus and the direction of their fins and body can indicate is location.

Feeding: Roi are omnivorous. Studies have shown a preference for small reef fish, but they are also commonly caught with crustaceans in their stomachs. They are not so voracious that they will eat anything presented, but food can make them curious.

Breaking Point: Roi demonstrate the threshold that exists for all fish species in that marginal reduction of standing stock will not impact their population. They may still recover from even relatively heavy, but dispersed fishing pressure. However, there exists a threshold beyond which populations are too depleted to replenish themselves. This threshold will vary based on complex coral reef variations, but will be observed by fishers. It is typically this threshold that marks the necessary shift from volunteer to professional fishing.

Holing Up: Roi will typically hide in holes, facing the entrance. Two or more roi may hide in the same hole. It is never ideal to shoot a roi that is in the hole with another roi. This is the rough equivalent of missing a shot at the second roi, and will have the same result. It is preferable to separate the roi before dispatching one, which can be done in a variety of ways. Once the roi are separated, the smallest should be dispatched first, as it has the most options for hiding places. Then proceed to the next smallest until only the largest remains. The largest will have the fewest options but may be the smartest, so variations on this recommendation can be employed.

Vocalizing: We observed roi emitting a series of rapid grunts after being shot. The mechanisms and reasons for this vocalization are not known, but it is likely desirable to keep these potential distress calls to a minimum by quickly and humanely dispatching roi. Roi may also make vocalizations while mating, but more information is needed before a mating call becomes a tool in the removal toolkit.

Diver Behavior

Approaching: Roi will be spooked if divers approach too closely. They are also able to hear bubbles, grunts, whistles, and clicks that are sometimes made when equalizing, or while SCUBA diving, and will associate these sounds with potential threats. If a diver's hand is flailing or any jerky motions are detected, roi will be spooked. The best approach is a steady moderately fast direct line from immediately above. Stop kicking within 10-15 feet of the roi and do not move, allowing momentum to close the gap. Shoot from 3-7 feet. Wary roi can be drawn out by staying below them, often just off the edge of the reef. They will swim higher in an effort to keep divers in sight and may be approached on a nearly parallel, but gradually intersecting course. At some point in each approach, the roi will present itself for a shot, so an awkward shot need not be forced. Over time divers will learn the conditions of this presentation under various conditions.

Aiming: The tip of the roi's head will often be visible peeking out from under a ledge or hole. Roi will not run toward open water, but will travel deeper into holes or along the edge of the reef. They can turn quickly so shots at stationary roi should be aimed at just behind the head, near the gill plate to cover any direction they may choose to go. If at the same depth as a moving roi, lead the roi toward its destination, which should be apparent based on where it swimming from/to.

Drawing Out: When roi are relatively unaccustomed to divers, they may be curious about artificial squid lures jigged 5-10 feet above the seafloor, sometimes travelling great distances to investigate. They will also swim freely between holes and may reveal other hiding roi in the process. They are drawn to chum or palu, including cut pieces of `ōpelu, but its use will draw other predators as well. It has been observed that the others in the harem will be drawn to a male that is dispatched and left on the bottom in the area of its harem mates. Dispatched roi can also be used at bait to draw in roi from other territories if they are weighted 1-6 feet above the bottom. Competitors will frequently leave their holes to investigate new roi in their territory. However, all bets are off for inspiring a wary harangued roi to leave its hole.

Pace: Roi respond to rapid movement and vibrations, so stay calm and purposeful in the water and work as a team taking turns distracting and dispatching roi as opportunities present themselves.

Teamwork: Calm teamwork is a good diving practice in general, and likely to contribute to much success in areas where roi are unaccustomed to divers as they will slowly but actively approach a slow moving diver or they will rest in holes in plain sight. Much success can be had when one diver holds the roi's attention by slowly waving their hand, wiggling finger, or moving a mop-head on a stick while the other diver sneaks up from out of sight. This is a highly effective method, but is most useful when SCUBA diving or diving in shallow water.

Caveats

Situations may arise, perhaps frequently, where this information is of no use or is the opposite of what works. If so, it would be great to add to this document or modify it based on local conditions, but that's up to the reader.

Even though diver behavior is considered, there are no safety recommendations made here. This is not because safety is not important, but because safe diving practices are too extensive for the purposes of this document – this is not a safety manual or dive plan. However, it is vital to consider such things as buddy system, dive profiles, boat traffic, safety floats, surface support, emergency contacts, first aid and CPR training, and many other things before each and every dive.

Additional Resources

Benthic Habitat Maps - http://ccma.nos.noaa.gov/products/biogeography/hawaii_cd_07/

Ciguatera Information - http://www.fish4science.com/

Maui County Invasive Species Management - http://co.maui.hi.us/index.aspx?NID=635

Roi Biology - http://www.fishbase.org/summary/Cephalopholis-argus.html

Special Activity Permit Application - http://hawaii.gov/dlnr/dar/pubs/SAP_application.pdf

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Supplemental Materials #4: Ciguatoxic Roi Distribution through 2011

Results of roi tested for ciguatera from tournament and community events on Hawaiʻi Island. Sample size (n) represents the number of roi tested from each event. Percentages show the relative percentage of fish testing positive for ciguatera by the lab of Dr. Paul Bienfang at UH Manoa. Locations and dates mark the geography and year of fishing activity.