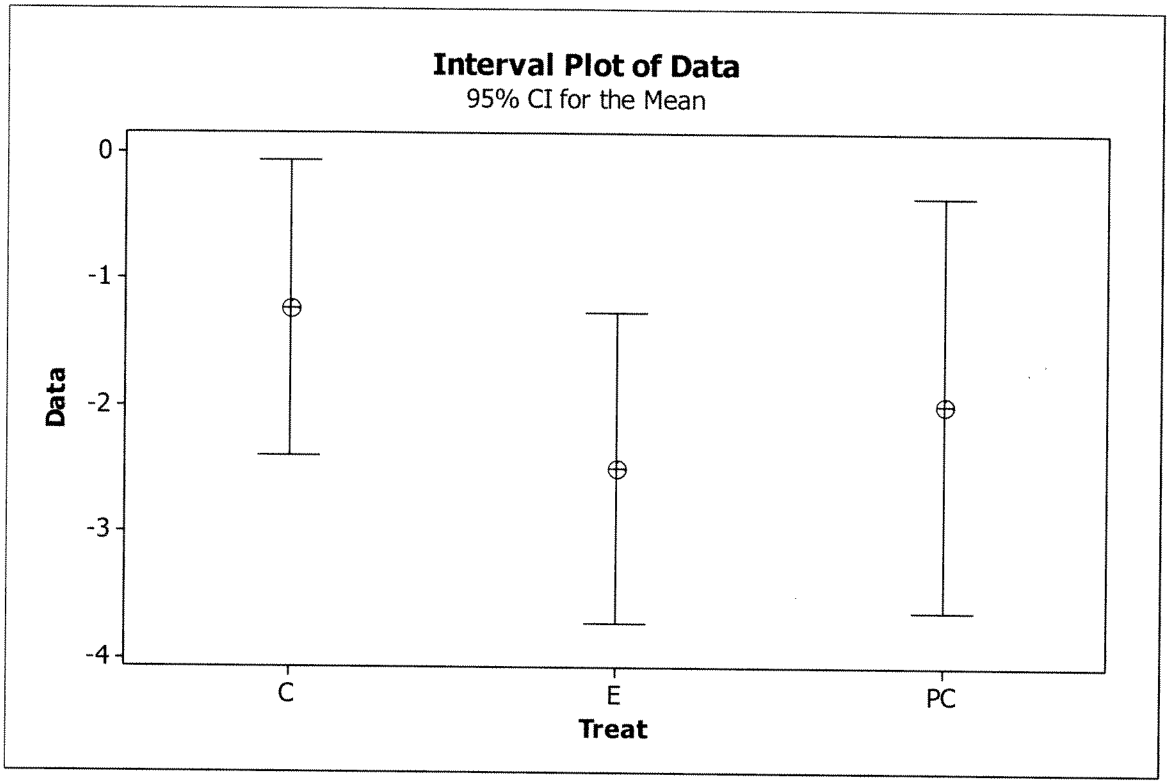
Statistical Ecology
Stat 555

Nested ANOVA

Urchin Experiment



```
MTB > Oneway 'Data' 'Treat'.
```

One-way ANOVA: Data versus Treat

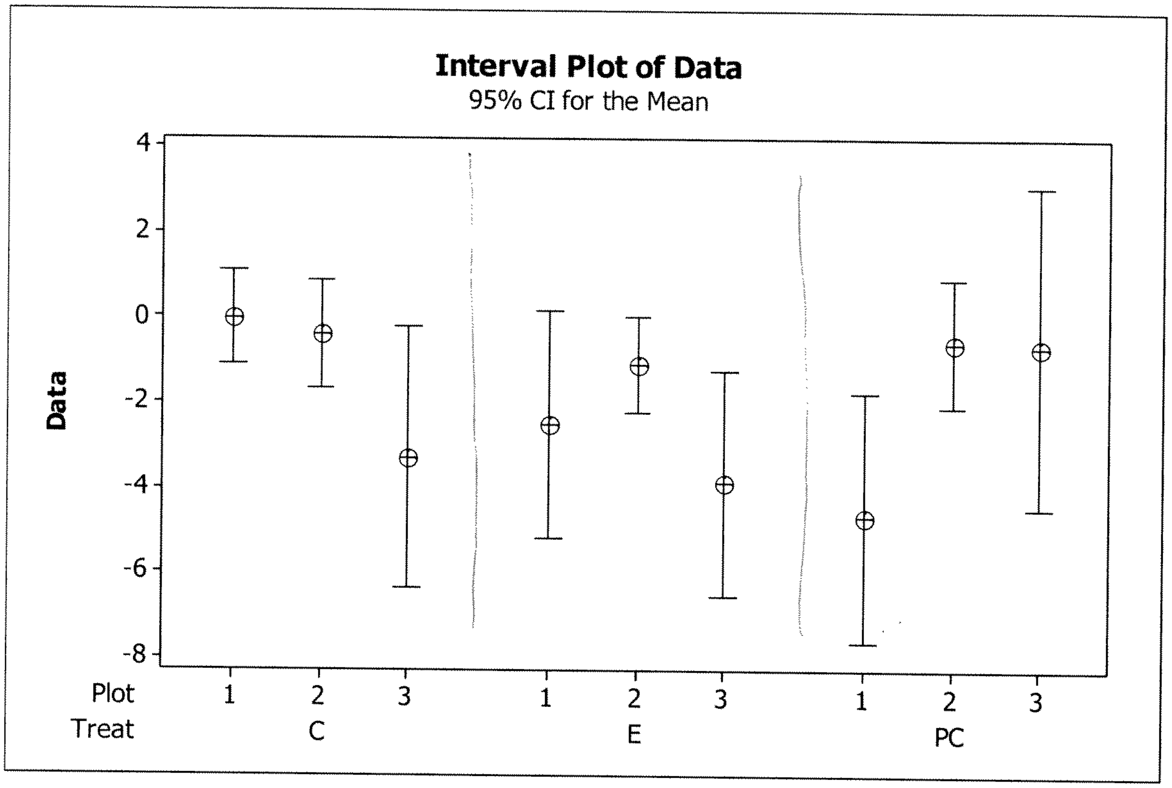
```
Source   DF      SS    MS     F      P
Treat     2    24.4  12.2  0.92  0.402
Error    87  1152.9  13.3
Total    89  1177.3

S = 3.640   R-Sq = 2.07%   R-Sq(adj) = 0.00%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level   N    Mean  StDev  --------+---------+---------+---------+-
C      30  -1.233  3.115              (-------------*------------)
E      30  -2.500  3.288  (------------*------------)
PC     30  -2.000  4.386       (------------*------------)
                          --------+---------+---------+---------+-
                               -3.0      -2.0      -1.0       0.0

Pooled StDev = 3.640
```

$H_0: A_C = A_E = A_{PC}$

or

$H_0: \mu_C = \mu_E = \mu_{PC}$

$$X_{ij} = \mu + A_i + e_{ij}$$



```
MTB > ANOVA 'Data' = Treat Plot( Treat);
SUBC>   Random 'Plot';
SUBC>   EMS;
SUBC>   Means Plot.
```

$H_{01}: A_C = A_E = A_{PC}$

$H_{02}: \sigma_B^2 = \phi$

ANOVA: Data versus Treat, Plot

```
Factor         Type    Levels  Values
Treat          fixed        3  C, E, PC
Plot(Treat)    random       3  1, 2, 3


Analysis of Variance for Data

Source        DF       SS     MS     F      P
Treat          2    24.42  12.21  0.34  0.723
Plot(Treat)    6   213.47  35.58  3.07  0.009
Error         81   939.40  11.60
Total         89  1177.29
```

✓ Accept H_{01}

✓ Reject H_{02}

```
S = 3.40551   R-Sq = 20.21%   R-Sq(adj) = 12.33%


                                          Expected Mean Square
                    Variance    Error     for Each Term (using
   Source          component    term      unrestricted model)
1  Treat                           2      (3) + 10 (2) + Q[1]
2  Plot(Treat)         2.398       3      (3) + 10 (2)
3  Error              11.598              (3)
```

17% — 2

83% — 3

$$X_{ijk} = \mu + A_i + B_{j(i)} + e_{ijk}$$

Examples of nested ANOVA

A. Cowry size: sampling locations nested within populations in one-way ANOVA

```
MTB > anova size=population location(population);
SUBC> random location;
SUBC> ems.
```

Analysis of Variance (Balanced Designs)

```
Factor                  Type Levels Values
Populati               fixed      4      1      2      3      4
Location(Populati)    random      2      1      2


Analysis of Variance for Size

Source                    DF         SS          MS        F        P
Populati                   3    1060.80      353.60    42.78    0.002 - Reject Ho
Location(Populati)         4      33.06        8.27     1.93    0.115 - Accept Ho
Error                     72     308.34        4.28
Total                     79    1402.20


Source                    Variance  Error  Expected Mean Square
                         component   term  (using unrestricted model)
 1 Populati                             2  (3) + 10(2) + Q[1]
 2 Location(Populati)       0.3982      3  (3) + 10(2)
 3 Error                    4.2826         (3)
```

Location	8.5 %
Within Sample	91.5 %

Pop's

Cocos-Keeling < Sample 1 / Sample 2

Phuket < 1 / 2

Oahu < 1 / 2

Hawaii < 1 / 2

$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$

H_A: at least one μ different

$H_0: \sigma^2_{Loc} = 0$

$H_A: \sigma^2_{Loc} \neq 0$

B. Abalone size: replication of transects in two factor ANOVA

```
MTB > anova size = pop wave wave*pop transect(wave);
SUBC> random transect;
SUBC> ems.
```

Analysis of Variance (Balanced Designs)

$H_0: \mu_1 = \mu_2$] – Pop
$H_A: \mu_1 \neq \mu_2$

$H_0: \mu_1 = \mu_2$] – Wave
$H_A: \mu_1 \neq \mu_2$

H_0: no interaction
H_A: interaction

$H_0: \sigma^2_{tran} = \emptyset$
$H_A: \sigma^2_{tran} \neq \emptyset$

```
Factor            Type Levels Values
Pop              fixed      2      1      2
Wave             fixed      2      1      2
Transect(Wave)  random      2      1      2


Analysis of Variance for Size

Source            DF        SS        MS      F      P
Pop                1   28275.8   28275.8  62.78  0.000 — Reject Ho
Wave               1     955.5     955.5   0.68  0.497 ]
Pop*Wave           1     339.3     339.3   0.75  0.387 ] – Accept Ho
Transect(Wave)     2    2814.8    1407.4   3.12  0.047 — Reject Ho
Error            154   69360.4     450.4
Total            159  101745.8


Source             Variance Error Expected Mean Square
                  component  term (using unrestricted model)
 1 Pop                          5 (5) + Q[1,3]
 2 Wave                         4 (5) + 40(4) + Q[2,3]
 3 Pop*Wave                     5 (5) + Q[3]
 4 Transect(Wave)     23.93     5 (5) + 40(4)
 5 Error             450.39       (5)
```

Transect	6%
Within Sample	94%

C. Coral cover: replication of transects in two factor ANOVA

```
MTB > anova coral = year depth year*depth transect(depth);
SUBC> random transect;
SUBC> ems.
```

Analysis of Variance (Balanced Designs)

```
Factor              Type  Levels Values
Year               fixed       3      1      2      3
Depth              fixed       3      1      2      3
Transect(Depth)   random       2      1      2


Analysis of Variance for Coral

Source                DF         SS         MS        F      P
Year                   2     5944.1     2972.1     3.16  0.048
Depth                  2    11787.3     5893.7     5.22  0.105
Year*Depth             4     4491.6     1122.9     1.19  0.320
Transect(Depth)        3     3384.1     1128.0     1.20  0.315
Error                 78    73300.1      939.7
Total                 89    98907.2
```

$H_0: \mu_1 = \mu_2 = \mu_3$] - Yea
H_A: one $\mu \neq$

$H_0: \mu_1 = \mu_2 = \mu_3$] - Dept
H_A: one $\mu \neq$

H_0: no interact
H_A: interact

$H_0: \sigma^2_{tran} = 0$
$H_A: \sigma^2 tran = 0$

Year 0.048 - Reject H_0

Depth 0.105, Year*Depth 0.320, Transect(Depth) 0.315 } - Accept H_0

```
Source               Variance Error Expected Mean Square
                     component  term (using unrestricted model)
 1 Year                          5    (5) + Q[1,3]
 2 Depth                         4    (5) + 15(4) + Q[2,3]
 3 Year*Depth                    5    (5) + Q[3]
 4 Transect(Depth)       12.55   5    (5) + 15(4)
 5 Error                939.74        (5)
```

Transect 1.3%
Within Sample 98.7%

Effects of Aquarium Collectors on Coral Reef Fishes in Kona, Hawaii

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Abstract: *No previous studies have conclusively documented the magnitude of the effect of aquarium collecting on natural populations. In Hawaii concern over the effects on reef fish populations of collecting for the aquarium trade began in the early 1970s, primarily in response to multiple-use conflicts between aquarium-fish collectors and recreational dive-tour operators. In 1997–1998 we used a paired control-impact design to estimate the effect of aquarium collectors. We compared differences in fish abundance along visual belt transects between collection sites, where collecting was known to occur, and control sites, where collecting was prohibited. To test the assumptions of our observational design, we surveyed a combination of species captured by aquarium collectors and those not captured. The extent of bleaching, broken coral, and coral cover was also surveyed. Seven of the 10 aquarium species surveyed were significantly reduced by collecting. The abundance of aquarium fish at collection sites ranged from 38% lower (*Chaetodon multicinctus*) to 75% lower (*C. quadrimaculatus*) than that at control sites. In contrast, only two of the nonaquarium species displayed a significant collection effect. There were no significant differences in damaged coral between control and collection sites to indicate the presence of destructive fishing practices. In addition, there were no increases in the abundance of macroalgae where the abundance of herbivores was reduced by aquarium collecting. Although our results suggest that aquarium collectors have a significant effect on the abundance of targeted aquarium fishes, better knowledge of the intensity and location of collecting activities is required to make a rigorous assessment of the effects of collecting on nearshore fish populations. Several lines of evidence suggest that the current system of catch reporting underestimates actual removals.*

Efectos de Colectores de Acuario sobre los Peces de Arrecifes de Coral en Kona, Hawai

Resumen: *La magnitud del efecto de la recolección para acuarios sobre poblaciones naturales no ha sido documentada concluyentemente en ningún estudio previo. La preocupación por los efectos de la recolección para el comercio de acuarios sobre las poblaciones de peces de arrecifes comenzó a principios de los años 70 en Hawai principalmente en respuesta a los conflictos de uso-múltiple entre colectores de peces para acuarios y operadores de viajes de buceo recreativo. En 1997–1998 utilizamos un diseño apareado de control de impacto para estimar el efecto de colectores de acuario. Comparamos diferencias en la abundancia de peces a lo largo de transectos visuales en sitios de recolección, donde se sabía que ocurría recolección, en relación con sitios control en los que la recolección estaba prohibida. Para probar los sopuestos de nuestro diseño observativo examinamos una combinación de especies capturadas por los colectores de acuario y otra de especies no capturadas. Se examinó también la extensión de blanqueo, coral roto y cobertura de coral. Siete de las 10 especies de acuario examinadas estaban reducidas significativamente por la recolección. Las abundancias de peces de acuario en sitios de recolección variaron de 38% menos (*Chaetodon multicinctus*) a 75% menos (*C. quadrimaculatus*) individuos que en los sitios control. En contraste, sólo dos de las especies no recolectadas para acuario mostraron un efecto significativo de recolección. No hubo diferencias significativas en el coral dañado entre los sitios control y de recolección que indiquen la presencia de prácticas pesqueras destructivas. Además, no hubo incrementos en la abundancia de microalgas donde la abundancia de herbívoros se redujo*

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control the abundance of algae on coral reef ecosystems, their removal may cause shifts in community structure (reviewed by Hixon 1997).

Our goal was to obtain quantitative estimates of the effects of aquarium collectors on fishes on the Kona coast of Hawaii. Moreover, in response to reports of broken and bleached coral associated with destructive fishing practices, we also investigated changes in the associated coral reef habitat at each study site.

Methods

Observational Design

We used a paired control-impact design to estimate the effect of aquarium collectors on reef-fish abundance. The magnitude of the effect was estimated by comparing fish abundance at collection sites where aquarium-fish collecting was known to occur with geographically adjacent control sites where collecting was prohibited. Because the study was initiated after collection had begun, we assumed there were no differences between control and collection sites in the abundance of aquarium fishes prior to the onset of aquarium harvesting (i.e., their natural abundances were similar) (Osenberg & Schmitt 1996). We also assumed that all differences between the control and collection sites were due to aquarium-fish collecting and not other factors, such as fishing. As part of our study design, we gathered data to test these assumptions.

We established four study sites that served as two replicate control-collection pairs (Fig. 1). One pair of study sites was located at Honokohau (lat 19°40.26′N, long 156°01.82′W) and Papawai (lat 19°38.83′N, long 156°01.38′W). Papawai, a fishery management area (FMA) where collection of aquarium fishes has been prohibited since 1991 (Department of Land and Natural Resources 1996), served as our control site. Honokohau was frequented by aquarium collectors and served as a collection site. This pair of sites is hereafter referred to as the Honokohau study area. The second pair of sites was located at Red Hill North (lat 19°32.90′N, long 155°57.74′W) and Red Hill South (lat 19°30.32′N, long 155°57.17′W). Red Hill South is an FMA where the collection of aquarium fishes has been prohibited since 1991 (Department of Land and Natural Resources 1996), and it served as our control site. Red Hill North was frequented by aquarium collectors and served as a collection site. This pair of sites is hereafter referred to as the Red Hill study area.

At each study site, four permanent 50-m transect lines were established at 10- to 15-m depths by installing stainless steel eyebolts at the beginning and end points of each line. Transects served as reference lines for both the fish and coral surveys. We used a visual strip-transect search method to estimate fish abundances (Sale & Douglas 1981). A pair of divers swam side by side down either side of the transect line and counted all fishes seen within a corridor 3 m wide and extending to the surface.

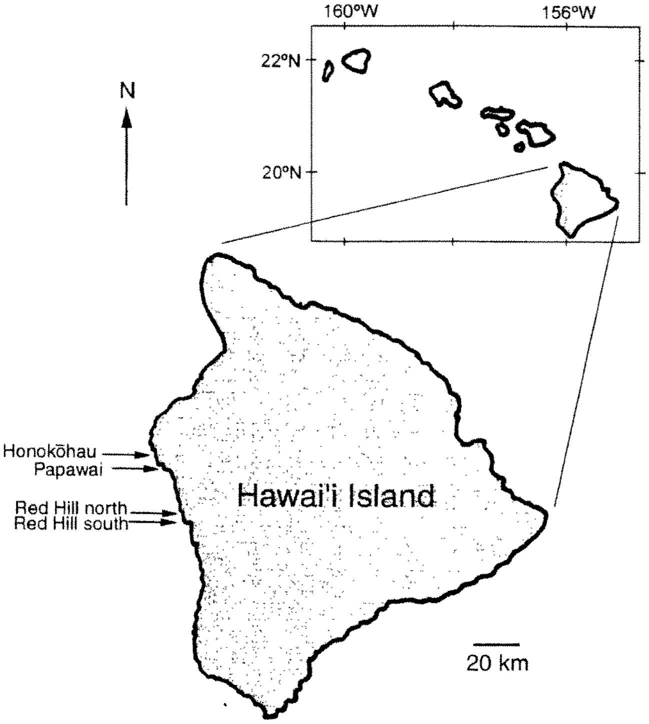

Figure 1. Map of study sites located off the island of Hawaii.

Surveys began at Honokohau in March 1997 and at Red Hill in September 1997 and ended at both areas in December 1998. All sites were sampled at 2- to 5-month intervals, for a total of eight surveys at Honokohau and five at Red Hill. During each survey we estimated the abundance of 21 fish species. These species included 11 aquarium fishes selected on the basis of high levels of capture, accounting for over 92% of the fish collected in Hawaii (DAR, unpublished data). Due to uncertainty in species identification, we pooled longnose butterflyfish as *Forcipiger* spp., which may include both *F. longirostris* and *F. flavissimus*, although most of the fish counted were probably the latter (personal observations). The remaining 10 fish species we surveyed were not targeted by aquarium collectors but were in guilds similar to those of collected species. These species were selected to provide tests of the assumptions of the observational design. Although the assumption of no difference between the control and collection sites prior to the study could not be tested directly, one prediction of this assumption was that uncollected species should not differ between control and collection sites. Accordingly, *Acanthurus nigrofuscus*, *A. nigroris*, *A. triostegus*, *Chaetodon lunulatus*, *C. unimaculatus*, *Paracirrhites arcatus*, *P. forsteri*, *Plectroglyphidodon johnstonianus*, *Stegastes fasciolatus*, and *Thalassoma duperrey* were also surveyed. The overall

Statistical Ecology
Stat 555

Nested Anova & Pooling

Use $p < 0.15$ as cutoff for pooling

```
    MTB > GLM  'ACAC' = Treatment Time( Treatment) Location
    Treatment*Location;
    SUBC>   Random 'Time'.

    General Linear Model: ACAC versus Treatment, Location, Time

    Factor             Type  Levels Values
    Treatmen          fixed      2  C  I
    Time(Treatmen)   random     16  1  2  3  4  5  6  7  8  1  2  3  4  5  6  7  8
    Location          fixed      2  1  2

    Analysis of Variance for ACAC, using Adjusted SS for Tests

    Source               DF     Seq SS     Adj SS     Adj MS      F      P
A   Treatmen              1     6.0096     7.2030     7.2030   9.95  0.005
B(A) Time(Treatmen)      14    10.1855    10.7504     0.7679   1.38  0.178
C   Location              1     1.1713     1.1713     1.1713   2.11  0.150
A*C Treatmen*Location     1     0.4033     0.4033     0.4033   0.73  0.396  Remove
    Error                86    47.6997    47.6997     0.5546
    Total               103    65.4694
```

$$X = \mu + A + B(A) + C + AC + e$$

```
MTB > GLM  'ACAC' = Treatment Time( Treatment) Location ;
SUBC>   Random 'Time'.

General Linear Model: ACAC versus Treatment, Location, Time

Factor             Type  Levels Values
Treatmen          fixed      2  C  I
Time(Treatmen)   random     16  1  2  3  4  5  6  7  8  1  2  3  4  5  6  7  8
Location          fixed      2  1  2

Analysis of Variance for ACAC, using Adjusted SS for Tests

Source          DF     Seq SS     Adj SS     Adj MS      F      P
Treatmen         1     6.0096     6.9602     6.9602   9.60  0.007
Time(Treatmen)  14    10.1855    10.3685     0.7406   1.34  0.201
Location         1     1.1713     1.1713     1.1713   2.12  0.149  Remove
Error           87    48.1030    48.1030     0.5529
Total          103    65.4694
```

$$X = \mu + A + B(A) + C + e$$

```
MTB > GLM  'ACAC' = Treatment Time( Treatment) ;
SUBC>   Random 'Time'.

General Linear Model: ACAC versus Treatment, Time

Factor            Type Levels Values
Treatmen         fixed      2 C I
Time(Treatmen)  random     16 1 2 3 4 5 6 7 8 1 2 3 4 5 6 7 8

Analysis of Variance for ACAC, using Adjusted SS for Tests

Source           DF     Seq SS    Adj SS    Adj MS     F      P
Treatmen          1     6.0096    6.9602    6.9602   9.78  0.006
Time(Treatmen)   14    10.1855   10.1855    0.7275   1.30  0.224   remove
Error            88    49.2743   49.2743    0.5599
Total           103    65.4694
```

$$X = \mu + A + B(A) + e$$

```
MTB > GLM  'ACAC' = Treatment

General Linear Model: ACAC versus Treatment

Factor     Type Levels Values
Treatmen  fixed      2 C I

Analysis of Variance for ACAC, using Adjusted SS for Tests

Source     DF    Seq SS    Adj SS    Adj MS      F      P          ok
Treatmen    1    6.0096    6.0096    6.0096  10.31  0.002
Error     102   59.4598   59.4598    0.5829
Total     103   65.4694
```

$$X = \mu + A + e$$

Table 1. Mean (SE) percent change in fish abundance between sites with aquarium-fish collection and without aquarium-fish collection for each study area.

		Percent change[a]								
		overall		*Honokohau*		*Red Hill*		*p*[b]		
Species	*df*	*mean*	*SE*	*mean*	*SE*	*mean*	*SE*	*effect (E)*	*area (A)*	*E ∗ A*
Aquarium species										
Chaetodontidae										
Chaetodon multicinctus	1,88	−38.2	6.57	−42.0	9.05	−32.3	9.63	0.02	-	-
Chaetodon ornatissimus	1,88	−39.5	20.2	−37.0	25.8	−43.4	36.4	-	<0.01	-
Chaetodon quadrimaculatus	1,87	-	-	−94.4	4.81	21.8	94.7	0.01	<0.01	-
Forcipiger spp.	1,86	-	-	−60.9	6.20	−43.6	19.5	0.01	<0.01	0.01
Pomacanthidae										
Centropyge potteri	1,87	-	-	−29.2	15.8	−73.1	12.3	0.03	<0.01	-
Acanthuridae										
Acanthurus achilles	1,88	−57.1	10.2	−64.0	13.3	−46.0	16.3	<0.01	-	-
Ctenochaetus strigosus	1,88	−14.7	8.20	−33.6	4.96	15.4	9.65	-	-	-
Naso lituratus	1,88	31.2	34.2	66.5	50.8	−25.2	25.1	-	-	-
Zebrasoma flavescens	1,87	-	-	−49.8	6.89	−43.2	6.47	<0.01	<0.01	-
Zanclidae										
Zanclus cornutus	1,88	−46.5	11.9	−45.9	16.1	−47.5	19.2	<0.01	-	-
Nonaquarium species										
Cirrhitidae										
Paracirrhites arcatus	1,86	-	-	−12.1	14.1	−75.3	3.16	<0.01	<0.01	<0.01
Paracirrhites forsteri	1,88	58.4	59.3	168.3	85.7	−73.6	14.5	-	-	-
Chaetodontidae										
Chaetodon lunulatus	1,88	−70.0	10.4	−70.0	10.4	-	-	-	-	-
Pomacentridae										
Plectroglyphidodon johnstonianus	1,88	−31.3	12.6	−12.1	15.2	−61.9	14.2	-	-	-
Stegastes fasciolatus	1,87	-	-	488	281	50.0	22.4	0.04	<0.01	
Labridae										
Thallasoma duperrey	1,88	17.4	12.4	31.6	17.0	−5.3	13.2	-	-	-
Acanthuridae										
Acanthurus nigrofuscus	1,87	27.3	22.8	15.2	26.7	46.7	43.5	-	<0.01	-
Acanthurus nigroris	1,88	67.2	63.6	−18.0	36.7	186.5	140.0	-	-	-
Acanthurus triostegus	1,88	−4.26	20.8	−5.68	32.4	<0.10	<0.10	-	-	-

[a] *A negative mean percent change indicates fewer individuals at effect relative to control sites.*

[b] *The* p *values and degrees of freedom (df) are reported for a two-way repeated-measure ANOVA on density.*

displayed a similar significant difference between control and collection sites at both study areas in which individuals were significantly more abundant at the control sites. These species, and the magnitude of their overall percent difference at collection sites, were as follows: *A. achilles*, −57%; *C. multicinctus*, −38%; and *Z. cornutus*, −47% (Table 1). (The negative percent indicates fewer individuals at collection than at control sites.)

Four species exhibited a significant collection and area effect (Table 1; Fig. 4). These species displayed significant differences between control and collection sites, but their overall abundance varied between study areas. Both *C. potteri* and *S. fasciolatus* were more abundant at Honokohau than at Red Hill, whereas *C. quadrimaculatus* and *Z. flavescens* were more abundant at Red Hill than at Honokohau (Fig. 4). The magnitude of their overall percent difference (in parentheses) at collection sites were as follows: aquarium species: *C. potteri*, −56%; *C. quadrimaculatus*, −75%; *Z. flavescens*, −46%; nonaquarium species: *S. fasciolatus*, +64% (Table 1).

Two species exhibited a significant collection-area interaction effect, where differences between control and collection sites varied between study areas (Table 1; Fig. 4). In the aquarium species *Forcipiger* spp., percent difference was greater at Honokohau (−61%) than at Red Hill (−44%). In contrast, the nonaquarium species *P. arcatus* displayed a lower percent difference at Honokohau (−18%) than at Red Hill (−75%) (Table 1; Fig. 4).

The overall fish community structure of the paired control and collection sites was remarkably similar. The H' diversity index at control and collection sites, respectively, was 1.18 and 1.16 at Honokohau and 1.16 and 1.17 at Red Hill. Similarly, the evenness index at control and collection sites, respectively, was 0.72 and 0.69 at Honokohau and 0.69 and 0.69 at Red Hill. At Honokohau, 44 species were seen at the control site, whereas 48 species were seen at the collection site. Forty-nine species were observed at both control and collection sites at Red Hill. Overall fish densities were 27% higher at Red Hill (mean density = 146 fish/100 m^2) than at Honokohau