An Abstract of the Thesis of

Gabrielle F. Renchen for the degree of Master of Science in Marine and Environmental Sciences presented on April 5, 2011

Title: Assessing the Ecological and Economic Impact of Derelict Fish Traps in the U.S. Virgin Islands

Abstract approved:

_____

Angela Dikou

Fish traps are a widely used fishing gear throughout the Caribbean, but become marine debris when lost or abandoned at sea. The impacts of derelict fish traps to coral reef ecosystems are uncertain as the relationships between flora and fauna interacting with the traps is rarely investigated. To examine the function of derelict fish traps in Caribbean coral reef ecosystems three primary questions were addressed using 12 experimental derelict fish traps; 1) Do derelict fish traps impact fishes through the process of ghostfishing?; 2) What are the behavioral interactions between fish and derelict traps?; and 3) What are the changes in fouling organisms and trap condition over time and can these changes be used to age traps?. Experimental derelict traps were deployed at inshore and offshore locations as well as in near-reef and far-reef habitats to study the impacts in a range of geographical locations and habitat types. To monitor ghostfishing, traps were monitored using visual observations using SCUBA three days a week for six months and, fouling organisms and trap condition were monitored once a month for 12 months. The behavioral relationships between fish and derelict traps were examined through the use of TrapCam, a custom built remote video surveillance camera system in an underwater housing. TrapCam recorded fish behavior in and around a derelict trap for fifteen, 24 hour periods. The results revealed that derelict fish traps do have the ability to ghostfish (n=453 fish), causing 5% mortality and subsequent economic loss ($26/trap/year), while damage to habitats was not observed. However, 95% of trapped fish eventually escaped with an average residence time of approximately 8 days. Trapped fish allocated the majority of their time to attempting to escape by butting into the trap mesh, with 5% causing damage to their bodies. Trapped fish did not experience a significant species effect for the time allocated to behavioral responses. Finally, changes in the structural condition of traps were not evident over the 12 month study period; however changes in fouling communities were observed both spatially and temporally. The results of this study provide quantitative data on the function and impact of derelict fish traps will provide valuable information to fishermen and managers about the efficiency of traps, susceptibility of species to capture and mortality and ecological relationships between fish species, sessile benthic communities and the persistence of derelict fish traps in tropical marine environments.

© Copyright by Gabrielle F. Renchen
April 5, 2011
All Rights Reserved

Assessing the Ecological and Economic Impact of Derelict Fish Traps in the U.S. Virgin Islands

By

Gabrielle F. Renchen

A THESIS

submitted to the

University of the Virgin Islands

in partial fulfillment of the requirements for the
degree of

Master of Science

Presented Date of Defense
April 5, 2011

Commencement
May 2011

Master of Science thesis of Gabrielle F. Renchen
presented on April 5, 2011

APPROVED:

Advisor - Dr. Angela Dikou

Committee Member – Dr. Simon Pittman

Committee Member – Dr. Marilyn Brandt

Director, MMES Program – Dr. John Barimo

Dean of the College of Science and Mathematics – Dr. Camille McKayle

I understand that my thesis will become part of the permanent collection of the University of the Virgin Islands Library. My signature below authorizes release of my thesis to any reader upon request

Student – Gabrielle F. Renchen

ACKNOWLEDGEMENTS

My committee: Dr. Simon Pittman, Dr. Angela Dikou and Dr. Marilyn Brandt

My amazing husband, Jeffrey Renchen, for being my best friend and an incredible source of support

My family, for their love, prayers and constant encouragement

Emily Speir, Caitlin Bartlett and Austin Luckett, for being incredible friends

My support in and out of the field:
Jeffrey Renchen
Robert Brewer
Bryan Legare
Steven Hitt
Leslie Henderson
Steve Prosterman
Ian Byrne
Dr. Rick Nemeth
Dr. Tyler Smith
Dr. John Barimo

My logistical and project support:
Randy Clark
Chris Caldow
Dr. Mark Monaco
Dr. Ron Hill
Dr. David Olsen

The local fishermen and the St. Thomas Fishermen's Association, for their input and interest in marine stewardship for the support of sustainable livelihoods

My funding sources:
The NOAA Marine Debris Program
Lana Vento Charitable Trust

CONTRIBUTION OF AUTHORS

Dr. Simon Pittman assisted with the overall project design as well as with data collection, interpretation and editing of Chapters 2 and 3. Randy Clark, Chris Caldow, Dr. Ron Hill and Dr. David Olsen assisted with the editing of Chapter 2. Dr. Marilyn Brandt assisted with interpretation of the data and editing of Chapter 3.

TABLE OF CONTENTS

Page

CHAPTER 1: GENERAL INTRODUCTION……. 2

CHAPTER 2: IMPACT OF DERELICT FISH TRAPS IN THE CARIBBEAN: AN EXPERIMENTAL APPROACH……...…..…. 5

2.1 INTRODUCTION……..... 6

2.2 METHODS…… 9

2.3 RESULTS……..…..... 12

2.4 DISCUSSION……..... 18

CHAPTER 3: UNDERWATER VIDEO ANALYSIS OF FISH BEHAVIOR IN EXPERIMENTAL DERELICT FISH TRAPS…….…. 32

3.1 INTRODUCTION……...….. 33

3.2 METHODS……..... 35

3.3 RESULTS……... 38

3.4 DISCUSSION……..... 41

CHAPTER 4: ASSESSMENT OF FOULING COMMUNITITES GROWING ON DERELICT FISH TRAPS IN THE CARIBBEAN...…. 55

4.1 INTRODUCTION……..……..... 56

4.2 METHODS…….……... 59

4.3 RESULTS……..…. 61

4.4 DISCUSSION…….… 65

CHAPTER 5: GENERAL CONCLUSION……..… 77

CHAPTER 6: BIBLIOGRAPHY……..... 80

TABLE OF CONTENTS (CONTINUED)

APPENDIX ……. 87

NON METRIC MULTI-DIMENSIONAL
SACLING OF FOULING COMMUNITY
SERIATION…… 88

LIST OF FIGURES

Figure Page

2.3.1 Diagrams of the chevron or arrowhead and rectangular traps used in the experimental derelict trap study……..…….. 25

2.3.2 Map of the study area on the southwestern shore of St. Thomas, U.S. Virgin Islands showing nearshore and offshore trap locations..... 26

2.3.3 Proportion of the total catch in experimental derelict fish traps grouped by fish family for a six month study period on the south shore of St. Thomas, U.S. Virgin Islands……..….. 27

3.3.1 Proportion of the total catch grouped by fish family for all 15 video samples……...… 49

3.3.2 Frequency distribution of the number of exits and entrances Recorded per hour in a day for all video samples…….….. 51

3.3.3 Proportion of individuals that escaped relative to their total catch by species…….….. 52

3.3.4 Grazing intensity per hour across all video samples……..…. 53

4.3.1 Groups with the highest percent cover growing over the inner mesh area at the inshore and offshore locations…….…... 72

4.3.2 Groups with the highest percent cover growing on the mesh at the inshore and offshore locations…….….. 73

4.3.3 Groups with the highest percent cover growing on the rebar at the inshore and offshore locations……...… 74

LIST OF TABLES

Table Page

2.3.1 Summary information for the experimental derelict traps……..….…. 28

2.3.2 Fish mortality in the experimental derelict fish traps during the six month ghostfishing study……..... 29

2.3.3 Fish behavior by fish family observed during the ghostfishing study……..… 30

3.3 1 The distinct identifiable fish behaviors observed from species caught inside the trap……..... 47

3.3 2 The distinct identifiable fish behaviors observed from species outside the trap…….….…..... 48

3.3.3 The percent of time the top ten most abundant species spent exhibiting the five most frequently recorded behaviors……... 50

4.3.1 Presence or absence of groups observed growing on the experimental derelict traps from January 23, 2010-January 23, 2011…… 70

4.3.2 ANOSIM analysis results comparing the percent cover of fouling community assemblages between locations and habitats…... 71

4.3.3 Index of Multivariate Seriation (IMS) values for each individual trap over the 12 month study period……..…. 75

APPENDIX FIGURES

Figure Page

1. Seriation of fouling communities growing on the rebar of trap 1, located at the offshore, near-reef site…… 88

1. Seriation of fouling communities growing on the rebar of trap 2, located at the offshore, near-reef site……... 88

3. Seriation of fouling communities growing on the rebar of trap 3, located at the offshore, near-reef site…… 89

4. Seriation of fouling communities growing on the rebar of trap 4, located at the offshore, far-reef site……..…… 89

5. Seriation of fouling communities growing on the rebar of trap 5, located at the offshore, far-reef site……..…… 90

6. Seriation of fouling communities growing on the rebar of trap 6, located at the offshore, far-reef site……..…… 90

7. Seriation of fouling communities growing on the rebar of trap 7, located at the inshore, near-reef site……..…… 91

8. Seriation of fouling communities excluding the effects of Hurricane Earl, growing on the rebar of trap 7……... 91

9. Seriation of fouling communities growing on the rebar of trap 8, located at the inshore, near-reef site……..…… 92

10. Seriation of fouling communities excluding the effects of Hurricane Earl, growing on the rebar of trap 8……... 92

11. Seriation of fouling communities growing on the rebar of trap 9, located at the inshore, near-reef site……..…… 93

12. Seriation of fouling communities excluding the effects of Hurricane Earl, growing on the rebar of trap 9……... 93

13. Seriation of fouling communities growing on the rebar of trap 10, located at the inshore, far-reef site……..…… 94

14. Seriation of fouling communities growing on the rebar of trap 11, located at the inshore, far-reef site……..…… 94

15. Seriation of fouling communities growing on the rebar of trap 12, located at the inshore, far-reef site……..…… 95

To my family,
Mom, Dad, Jeremiah, Jeffrey
Nanny and Papaw and Grandma and Poppie,
who have supported me through everything

Assessing the Ecological and Economic Impact of Derelict Fish Traps in the U.S. Virgin Islands

By

Gabrielle F. Renchen

A THESIS

submitted to the

University of the Virgin Islands

in partial fulfillment of the requirements for the
degree of

Master of Science

Presented Date of Defense
April 5, 2011

Commencement
May 2011

CHAPTER 1: GENERAL INTRODUCTION

Marine debris is any persistent, man-made material that has been intentionally or unintentionally disposed of in the marine environment (Stefatos et al. 1999). As the global population continues to grow and consumption of man-made materials increases, the accumulation of marine debris in the world's oceans has become a concern (Bauer et al. 2008). The types and sources of marine debris are numerous, but common items include plastics, glass, fishing gear and vessels (NOAA MDP 2011). Marine debris can pose a number of threats to both humans and marine species including navigational hazards, ghostfishing, degraded water quality, decreases in aesthetic value of marine areas and economic loss (Corbin et al. 1993).

Derelict fishing gear is a common type of marine debris typically associated with areas of concentrated fishing efforts (Hess et al. 1999). Used widely throughout the Caribbean to catch finfish and crustaceans (Recksiek et al. 1991), derelict fish traps likely comprise a large portion of the submerged marine debris (Macfadyen et al. 2009). Derelict traps occur as a result of several processes including: intentional abandonment of old and damaged traps; movement of traps and or loss of trap markers from the entanglement of trap lines with boat propellers or other gears; fouling on the benthos (i.e., traps and ropes become caught on rocky substrates); human error and inclement weather (Laist 1995, Renchen et al. in review).

Derelict fish traps are typically constructed of wire and rebar and are often observed overgrown by fouling organisms typically composed of sessile benthic communities, suggesting that they persist in the marine environment for many years. While a fair amount of work has been done studying the selectivity (Munro et al. 1971; Gobert 1998) and amount of bycatch (Olsen 2008) in active fish traps, little

research has experimentally examined the function of derelict fish traps as part of a coral reef ecosystem in terms of the impacts to species and habitats, relationships between traps and fish behavior and growth of fouling communities.

The impetus for this study emerged from the need for a greater scientific understanding of derelict fishing gear and the problem of derelict fish traps as identified by: 1) the commercial trap fishermen of St. Thomas and St. John trap fishery interested in evaluating current fishing practices to ensure they are consistent with the maintenance of a viable long-term trap fishery; and 2) federal marine management agencies interested in the reduction of marine debris and enhanced marine stewardship. This study provides the first experimental assessment of the biological and physical impacts associated with derelict traps in the Caribbean as well as the potential impacts to the U.S. Virgin Islands' fishery. It also provides the first experimental assessment of trap fauna relationships including the behavior of fish in response to traps and the function of derelict traps as artificial reefs. The primary objectives of this research were to determine: 1) if ghostfishing occurs in derelict fish traps and quantify its magnitude, 2) how fish respond to derelict fish traps and quantify behavioral allocation and 3) how derelict traps function as part of a coral reef ecosystem in terms of providing artificial substrate for fouling organisms.

CHAPTER 2: IMPACT OF DERELICT FISH TRAPS IN THE CARIBBEAN: AN EXPERIMENTAL APPROACH

Gabrielle F. Renchen, Simon J. Pittman, Randy Clark, Chris Caldow, David Olsen and Ron Hill

Fisheries Research
http://www.elsevier.com/wps/find/journaldescription.cws_home/503309/description#description
Manuscript Number: FISH3443, under review

2.1 INTRODUCTION

Fish traps are an effective and economically important multi-species fishing gear used widely for harvesting crustaceans and finfish around the world (Recksiek et al. 1991). Like many marine industries, trap fisheries contribute to marine debris through the accidental loss or abandonment of gear at sea. Lost and abandoned traps, also referred to as derelict traps, occur as a result of several processes including: intentional abandonment of old and damaged traps; movement of traps and or loss of trap markers from the entanglement of trap lines with boat propellers or other gears; fouling on the benthos (i.e., traps and ropes become caught on rocky substrates); human error and inclement weather (Laist 1995). Although few studies have examined the impact of derelict fish traps, it is widely thought that traps "ghostfish", a term used to describe the process by which derelict fishing gear continues to catch fish and induce mortality in an uncontrolled manner (Matsuoka et al. 2005; Smolowitz 1978).

The phenomenon of ghostfishing and other behavioral interactions between marine fauna and derelict traps is rarely studied experimentally, even in the world's major trap fisheries. We conducted a literature search using Cambridge Scientific Abstracts and found that only seventeen trap studies focused on ghostfishing between 1980 and 2010, the majority of which were from large scale temperate water fisheries. No studies were found for coral reef fisheries or the Caribbean. Controlled *in-situ* experiments, however, can provide reliable information on the occurrence and magnitude of impacts that will help fishing communities and marine managers decide if action is necessary to mitigate threats.

In the U.S. Virgin Islands, the trap fishery is the largest economic component of the local multi-gear, multi-species fisheries, accounting for approximately 37% of the total landings and revenue (Agar et al. 2005). Trap fishing also has significant cultural and heritage value for the island communities; the technical skills, environmental knowledge and culture of the trap fishery have persisted through generations for over 150 years.[1] The commercial trap fishery in St. Thomas, with average annual landings from 2000-2008 of 447,000 lbs. (91,500 lobster, 355,000 finfish) and an average of 379,000 trap hauls (D. Olson, pers. comm.), while relatively small-scale compared to continental commercial fisheries, provides critical access to valuable marine resources with 100% of the produce sold for local consumption by residents and tourists. Approximately 3,662 fish and 2,446 lobster traps are fished between St. Thomas and St. John (T. Blanchard-pers. comm.)[2]. Unlicensed subsistence trap fishing also occurs, yet is poorly documented in the region.

In the Caribbean region, traps are commonly used to catch lobster and fish associated with coral reef ecosystems (Gobert 1998; Hawkins et al. 2007). The U.S. Virgin Islands trap fishery is a multi-species fishery, mainly landing parrotfish, grunt, triggerfish, grouper, snapper and spiny lobster; however many more non-target species are caught and subsequently discarded because of size restrictions, food preferences, or risk of ciguatera poisoning (Olsen 2008). The most commonly used fish trap designs are chevron and rectangular traps constructed of steel rebar or wood, while lobster traps are typically constructed of plastic or metal and wood. Traps are sometimes set and fished individually, but in many cases, particularly for commercial fishing, multi-trap strings are deployed (Sheridan et al. 2006).

In the U.S. Virgin Islands, commercial shipping (i.e. cruise ships, cargo ships) is reported by fishermen as a major cause of trap loss, since some of the most productive fishing grounds coincide spatially with commercial shipping routes presenting an important challenge for future marine spatial planning in the region. In addition, information from local fishermen suggests that hurricanes and other weather events promote trap loss and that disposal of unused traps at sea is common practice. Once derelict, hurricanes, severe storms and swell events can mobilize traps, but quantitative data on trap movement and associated impacts to benthic communities are rare and the magnitude of impacts uncertain (but see Lewis et. al. 2009).

Our study provides the first experimental assessment of biological and physical impacts associated with derelict traps in the Caribbean, as well as, the potential economic impacts to the U.S. Virgin Islands' fishery. The impetus for this study emerged from the need for a greater scientific understanding of derelict fishing gear and the problem of derelict traps as identified by: 1) The commercial trap fishermen of the St. Thomas and St. John trap fishery interested in evaluating current fishing practices to ensure they are consistent with the maintenance of a viable long-term trap fishery; and 2) Federal marine management agencies interested in reduction of marine debris and enhanced marine stewardship for ecosystem health and sustainable livelihoods.

The primary objective of this study was to determine if ghostfishing occurs in derelict traps and to quantify its magnitude by determining the species, abundance and size of fish that were injured or killed. We also wanted to quantify the duration of entrapment for individual fish and determine if spatial effects influenced the

composition and amount of ghostfishing. Derelict traps may function as artificial reefs or nursery habitat for juvenile fish especially in areas with low structural complexity; thus another objective was to quantify this potentially positive effect on the marine environment that is rarely discussed. The final objective, although opportunistic, was to determine if trap movement occurs and to quantify any damage to the seafloor communities if trap movement was detected.

Specific hypotheses were formulated and tested for all habitat strata:

H_1: Derelict traps with escape panels closed cause fish mortality

H_2: Derelict traps with open escape panels result in lower residence time and mortality than traps with closed escape panels

H_3: Assemblage composition and residence time of trapped fish is significantly different between habitat strata (inshore/offshore/close and far from reefs).

2.2 METHODS

Trap design

Two fish trap designs were used for experimental fishing: 1) the chevron or arrowhead trap, and 2) the more common rectangular trap (Figure 1). All traps were constructed by a local St. Thomas fisherman, with a steel rebar frame, horseneck funnel and two inch vinyl coated square mesh. The escape panels on the sides of the traps were tied closed with 1/8 inch diameter untreated jute twine. Closed traps were designed to simulate an actively fishing trap that has become lost.

Study sites and sampling designs

A total of twelve experimental traps were deployed using a stratified sampling design that included near-reef and far-reef habitats at both nearshore and offshore stations. Benthic habitat strata were defined using NOAA's benthic habitat maps (Kendall et al. 2001) followed by underwater reconnaissance. The strata used for both locations consisted of: 1) sand immediately adjacent to a coral reef (within 1m); and 2) sand or seagrass more distant from coral reefs (≥ 80 m). The inshore location, Perseverance Bay (18°20'22.96" N 64°59'34.73" W), is an open bay on the southern shore of St. Thomas, U.S. Virgin Islands, while the offshore location, Flat Cay (18°19'00.86" N 64°59'22.96" W) is a small uninhabited island approximately two kilometers south of Perseverance Bay (Figure 2). Both locations had been fished with traps historically as evidenced by sightings of derelict fish traps and actively fished traps. Six traps were deployed with escape panels closed (henceforth referred to as closed) and six with escape panels open (henceforth referred to as open). In addition, permanent markers (metal stakes) were placed into the substratum at 40 cm from two sides of each trap to allow monitoring of physical movement caused by storm conditions.

Traps were surveyed using SCUBA three days a week from January 2010 to July 2010 with 53 surveys conducted for offshore traps and 58 for inshore traps. Field observations included visual surveys of the trap contents including the abundance of fish species and estimated body length (total length) to the nearest centimeter. Observations were also recorded on the behavioral interactions of trapped fish to one another and were classified into the following categories; an individual attempting to escape (IATE), a school of fish attempting to escape (SCATE), fish aggregating in one

area of a trap (AGG), fish schooling with no attempts at escape (SC), an individual swimming about the trap with no attempts at escape (ISW), an individual sitting calmly in one area of a trap (C), an individual avoiding other fish (AV) and individuals displaying aggression towards other fish (AGR). Attempting to escape was defined as fish seen banging into the mesh or corners and or poking their heads through the mesh. The physical condition (i.e. scrapes, bruising, etc.) and mortality were also recorded. Behavioral observations were recorded at a distance to reduce the effect of a diver's presence on the fish. The abundance, size and general behavior of fish within one meter of the trap were recorded. All species and individual fish were photographed to aid in estimation of residence times in traps, and to assess any physical damage to the fish.

Data analysis

A two-way analysis of variance (ANOVA) was used at both the species and family level to test for between-location differences in the maximum number of consecutive days (log transformed) fish spent in the traps. Differences were tested for both inshore and offshore locations and near-reef and far-reef habitats. A maximum number of consecutive days was used because the experimental traps could not be visited on a daily basis, therefore the number of days fish spent in traps was estimated from fish presence on previous sampling dates. The Wilcoxon test was used to test for differences in mortality between inshore and offshore locations. We applied a suite of multivariate analyses in PRIMER v6 software (Clarke and Warwick 2001) to examine differences and similarities in fish assemblages by location. Non-metric multi-dimensional scaling (nMDS) was used to visually compare assemblage similarities,

analysis of similarities (ANOSIM) to test for significant differences and similarity percentages (SIMPER) to determine the contribution of species to assemblage dissimilarity. Since we were primarily interested in evaluating ghostfishing, we conducted multivariate analyses only on closed traps as open traps were not predicted to trap fish. Untransformed presence-absence data was used rather than abundance to avoid the confounding effect from repeat counts of the same individual over multiple trap surveys.

The value of commercial fish during the study period was obtained from the St. Thomas Fishermen's Association and from the local fish markets. The weight of individual fish species was calculated using the length-weight relationship, $W=aL^b$, with *a* and *b* parameters for each species collected from FishBase (Froese and Pauly 2010). Weight was used to calculate market prices (USD per lb) for an estimation of economic loss.

2.3 RESULTS

Summary catch statistics

During the six month study period, 453 fish comprising 21 families and 42 species were observed within the six closed experimental traps (Figure 3). The most frequently observed families were: surgeonfish (*Acanthuridae*, n=131 individuals); snapper (*Lutjanidae*, n=63); porgy (*Sparidae*, n=47); angelfish (*Pomacanthidae*, n=39); and boxfish (*Ostraciidae*, n=38). The most frequently observed species were: blue tang (*Acanthurus coeruleus*, n=67 individuals); doctorfish (*Acanthurus chirurgus*, n=47); saucereye porgy (*Calamus calamus*, n=47); schoolmaster snapper (*Lutjanus apodus*, n=40); gray angelfish (*Pomacanthus arcuatus*, n=33); and smooth trunkfish

(*Lactophrys triqueter*, n=32). The minimum and maximum total lengths (TL) recorded for trapped fish were 4 cm and 107 cm respectively, with a mean size of 21.1 cm (± 5.41cm). The smallest individual caught was a peacock flounder (*Bothus lunatus*, 4 cm TL) and the largest was a nurse shark (*Ginglymostoma cirratum*, 107 cm TL). During the study the average biomass observed in closed traps was 0.85 lbs (± 0.719 lbs) ranging from 0.00082 lbs to 17.12 lbs.

A total of 1,272 fish comprising 14 families and 27 species, were observed within the six open experimental traps. The most frequently observed families were: grunts (*Haemulidae*, n= 952); snapper (*Lutjanidae*, n= 124); surgeonfish (*Acanthuridae*, n= 44); goatfish (*Mullidae*, n= 38) and squirrelfish (*Holocentridae*, n= 29). The most frequently observed species were: tomtate (*Haemulon aurolineatum*, n= 799), lane snapper *(L. synagris*, n= 89), bluestriped grunt (*H. sciurus*, n= 79), french grunt (*H. flavolineatum*, n= 67) and spotted goatfish (*Pseudupeneus maculatus*, n= 38). The minimum and maximum lengths recorded for fish in open traps was 2 cm (ocean surgeonfish, A. *bahianus*) and 25 cm (trunkfish, *L. trigonus*), with a mean size of 7.94 cm (± 0.98 cm). The average biomass observed in open traps was 0.021 ± 0.017 lbs ranging from 0.00043 lbs to 0.80 lbs.

Fish Assemblage Comparisons

The composition of fish assemblages in closed traps was significantly different between inshore and offshore locations (ANOSIM R= 0.23, p= 0.001) and between near-reef and far-reef habitats (ANOSIM R= 0.2, p= 0.001). However, the ANOSIM test and nMDS ordination plots (not shown) revealed very high assemblage similarity between locations with no clear separation in assemblage composition. The nMDS

plot provided a good two-dimensional representation of the multivariate assemblage data as indicated by a low stress value (0.01) for all plots. Despite high overlap, differences in the prevalence of seven species contributed approximately 60% to the assemblage differences at inshore and offshore locations. *P. arcuatus, A. coeruleus and A. chirurgus* were more prevalent in offshore traps contributing 11.8%, 8% and 7.8% to the difference, respectively. *L. apodus, L.triqueter, G. cirratum and C. calmus* was more prevalent in inshore traps and contributed 9.9%, 8.9%, 7.6% and 4.6% to the difference, respectively.

Differences in the prevalence of eight species contributed approximately 60% of the difference between trap assemblages at near-reef and far reef habitats. *C. calamus, H. sciurus* and *L. triqueter* contributed 9.9%, 8.72% and 5.73% to the difference, respectively, with higher prevalence in far-reef traps. More prevalent in near-reef traps, *L. apodus, P. arcuatus, A. chirurgus, A. coeruleus and G. cirratum* contributed 7.7%, 6.6%, 5.7%, 5.3% and 4.9 % to the difference, respectively.

Residence time

Fish species spent an average of 8.2 (±3.4) consecutive days in the closed traps and a median of 5.5 days. There was a significant difference in the residence time between inshore and offshore locations for the top five most prevalent species (df = 233, $p < 0.001$) and families (df = 317, $p<0.001$). Species and families caught inshore spent approximately four and 2.5 more days, respectively, in the traps than those caught offshore. In both cases there was a significant interaction for the effect tests of species and locations (df = 4, $p = 0.049$) and family and location (df = 4, $p = 0.002$). There was also a significant difference in the residence time of the top five species

caught between near-reef and far-reef locations (df = 233, p= 0.002) and between families (df = 317, p=0.001). Species and families caught at far-reef locations spent approximately two more days in the traps than those caught in near-reef locations. Significant interactions were not present for the effect tests of species and habitat (df = 4, p= 0.07) and family and habitat (df =4, p= 0.11).

Ghostfishing mortality and bodily damage

Ninety-five percent of fish (433 individuals) were able to escape the closed traps. Twenty fish (~5%) were unable to escape and subsequently died. The average mortality ratio (# of mortalities/total # caught in all traps) was higher in inshore traps than those offshore and higher in far-reef versus near-reef traps (Table 2.3.1). All but one of the mortalities observed were from closed traps, with one expired individual (a barracuda, *Sphyraena barracuda*) observed in a trap with the escape panels open. Dead fish, their skeletal remains, and in some cases fleshy remains, were observed in all of the traps that incurred known mortalities. Invertebrate species found feeding on fish carcasses included *Creaster reticulates* (cushion seastar) and *Hermodice carunculata* (bearded fireworm). No significant difference was detected in the mortality ratios between inshore and offshore locations (Wilcoxon Z=-1.24, p= 0.21) or between near-reef and far-reef habitats (Wilcoxon Z= -0.25, p= 0.80). The temporal distribution of mortality ranged from 1-5 mortalities per month. Mortalities were highest during the first and fourth months of the study (five mortalities), and lowest during the last month (one mortality). Months two, three, and five fluctuated from two to four mortalities per month.

Using the price per pound for each species, the 20 mortalities (total 51 lbs) amounted to an economic loss of 160 USD over the six month study period. This is equivalent to an average of approximately 26 USD per trap per year (Table 2.3.2).

Approximately 5% of all trapped fish were observed with skin wounds or abrasions, while 20% of those that died had abrasions on their snouts and or foreheads due to repeatedly butting into the mesh while trying to escape. Species that were seen on multiple occasions with injuries included *Sparisoma viride*, *C. calamus*, *Ocyurus chrysurus* and *L. triqueter*. The number of fish injured that died in inshore traps was two times higher than those caught in offshore traps; however the number of injured fish that died in near-reef traps was only slightly higher than those caught in far-reef traps. Within the fish families affected by mortality, it was typically a single species that was impacted. Snappers (*Lutjanidae*) and boxfishes (*Ostraciidae*) experienced mortality in three and two species respectively. The species that experienced the most mortality were *Aluterus scriptus (100%)*, *S. barracuda* (100%), *L. jocu* (67%), *O. chrysurus* (25%) and *Acanthostracion quadricornis* (25%). Fish species with a depressed body shape (e.g. *G. cirratum*) accounted for the highest percentage of mortalities (17%). The elongated (e.g. *S. barracuda*), fusiform (*O. chrysurus*), deep or short (*C. calamus*) and laterally compressed (*P.arcuatus*) body shapes had 10%, 4.6%, 4.2% and 2.3% species mortality, respectively.

Fish behavior

A wide variety of fish behavioral interactions were observed in the traps. Although behaviors appeared to be family specific, multiple behaviors were expressed among individual species and families (Table 2.3.3). Seventy-two percent of the fish

families were observed attempting to escape as either a school or as an individual. Fish attempting to escape did so by swimming throughout the trap, often banging into the mesh, looking for an exit particularly at the corners of the trap. Species most often observed banging into the mesh included *C. calamus*, *O. chyrsurus*, *L. jocu* and *S. viride*. Other behaviors observed included fish continuously swimming as individuals or as a school without banging into trap mesh, aggregating in one area of the trap, avoiding other fish, showing aggression towards other fish, and calmly sitting stationary in one area of the trap. *A. chirurgus*, *A. coeruleus* and *A. bahianus* were most often observed swimming continuously in schools, but also as individuals if conspecifics were not present in the trap. Aggregating species included *H. sciurus*. *H. plumierii*, *L. synagris*, *L. analis* and *C. calamus*. Grouper species such as *Epinephelus guttatus* and *E. striatus*, as well as the schoolmaster snapper, *L. apodus*, were observed avoiding other fish. *E. guttatus* a*nd P. arcuatus* were the two species observed displaying aggression and territoriality to both conspecifics and other species.

Derelict traps as fish attracting devices (FADs)

A total of 11,316 fish were observed within one meter on the outside of both the open and closed traps. Only 85 fish were observed within one meter of the traps located offshore, while 11,231 were observed at the inshore traps. Far-reef habitat traps had more fish located within one meter of the traps than those in near-reef habitats with 10,737 and 329 fish observed, respectively. Approximately 97% of fish observed within one meter of the traps were located at the inshore seagrass bed. The tomtate (*H. aurolineatium*), was most abundant accounting for 85% of all observed species. The spotted goatfish (*P. maculatus*), yellowtail snapper (*O. chrysurus*),

striped parrotfish (*Scarus iserti*) and bar jack (*Caranx ruber*) comprised the remainder of the top five species. Species documented at the seagrass traps were juveniles that slowly began to recruit to the traps during February and March of 2010, the second and third months of the study. The juveniles appeared to remain close to the traps as the cohorts were observed growing in size over the six months from post-settled juveniles to larger juveniles.

Storm-induced trap movement

Movement was noted for seven and measured for four traps after the passage of Hurricane Earl through the territory on August 30-31, 2010. The eye of the storm passed within 69 miles of the study site and wind speeds in excess of 70 mph and a storm surge of 1-3 ft were recorded (NHC 2010; Gutro 2010). Three traps located in shallow inshore waters (20 ft depth) moved distances of approximately 20 m, 133 m and 155 m from their original locations. Three other inshore traps moved and have not been recorded. One offshore trap located in 40 ft of water moved approximately 3m. Visual surveys of the seafloor conducted between the original locations and the post-hurricane locations for both the inshore and offshore traps revealed no obvious trap related damage to the substratum in September 2010 (1-2 weeks after the hurricane had passed).

2.4 DISCUSSION

Responsible management of fisheries impacts is essential to sustainable fisheries and the maintenance of fisheries livelihoods. In the Caribbean, high uncertainty exists regarding the impacts of derelict fish traps due to the lack of targeted scientific studies. Using controlled field experiments we have provided

quantitative data on mortality associated with derelict fish traps in the U.S. Virgin Islands, as well as information on a wide range of associated behavioral interactions. Reliable impact assessment is required to inform fishing communities and management agencies to help prioritize actions that may include design modifications to gears and fishing practices and mitigation actions such as trap disposal programs.

Overall, fish mortality was unexpectedly low, with 95% of fish able to leave the traps unaided. Nevertheless, our experimental derelict fish traps did result in fish mortality, therefore demonstrating that ghostfishing does occur with intact DFTs with escape panels closed. In contrast, when escape doors were open, prolonged entrapment and subsequent mortality was very rare (i.e. only one barracuda (107cm TL) died from six open traps deployed continuously for six months). The extrapolation of our mortality rates and costs/trap are low compared to the scale of the commercial fishery in St. Thomas, U.S. Virgin Islands. The average biomass/trap caught in our study as well as the percent mortality were approximately two to three times lower than estimates from a bycatch study conducted by the St. Thomas Fishermen's Association which indicated an average biomass/trap of 2.2lbs and 9% mortality (Olsen 2008). Little is known, however, about the condition of genuine DFTs, although it is likely that they exist in a range of conditions from intact and newly lost to damaged, eroded and intentionally discarded. Anecdotal information from local fishermen indicated that traps disposed of at sea are typically discarded with escape doors intentionally opened or removed to minimize risk of ghostfishing. Our experimental results suggest that this practice will almost entirely eliminate the risk of ghostfishing in derelict fish traps, although the presence of intact mesh may still, albeit rarely, result in mortality and

sub-lethal physical damage due to fish panic behavior. Behavioral observations indicated that a majority of the fish caught in the traps attempted to escape by banging into the mesh, often leaving bruises and abrasions on the area between the eyes and snout on the fish. Species that experienced stress and or injuries while trapped may have experienced post-escapement mortality due to infection from abrasions, although this was not evaluated during our study (Al-Masroori et al. 2004; Bullimore et al. 2001).

In a shorter duration study, Munro et al. (1971) documented 50% escapement after traps had soaked for 14 days. Munro (1974) also suggested that gradually more fish escape during each successive soak day, but that conspecifics may attract fish into traps. We observed fish of the family *Acanthuridae*, *Sparidae*, *Ostraciidae* and *Haemulidae* interacting with conspecifics in experimental DFTs when exhibiting schooling behavior inside the traps, entering and exiting traps and swimming alongside an untrapped conspecific on the outside of the trap. Similar conspecific behavior has also been extensively examined by Luckhurst and Ward (1987).

Offshore traps had higher species richness than inshore traps, but the average total length of fish caught was slightly smaller than those caught inshore. Environmental differences such as distance from shore, depth and vertical relief between locations may also contribute to differences in what species were caught and how they behave (Brokovich et al. 2006). Smith et al. (2008) documented that reef complexes in the U.S. Virgin Islands are influenced by their distance from shore; the mid-shelf island of Flat Cay was found to have lower sedimentation rates, higher coral cover and overall better coral health than the nearshore site of Perseverance Bay.

Residence time differences of fish caught in near-reef and far-reef habitats may be due to the difference in habitat structure and reef complexity as well as the catch composition. Certain species may be more accustomed to navigating reefs and swimming through crevices and therefore may enter traps more than other species but spend less time in the traps (e.g. squirrelfish, surgeonfish) (Robichaud et al. 2000). Traps, at some distance from a reef, may provide a temporary structural refuge that is otherwise lacking; fish in traps near the reef may not need to use the trap for cover (Wolff et al. 1999). Interestingly, the average number of consecutive days fish spent in traps corresponds closely with the reported average soak time of seven days utilized by local fishermen in the U.S. Virgin Islands (STFA pers. comm.).

Some fish species appeared to take up residency in the traps and were recorded on subsequent sampling dates over periods of almost three months before escaping or expiring. On return surveys, fish were identified from photographs and size estimates. This may have led to some confounding of estimates of residence times, particularly where conspecifics had few distinguishing features. Future studies could use a mark or tag to provide greater certainty in identification of individuals (Bullimore et al. 2001).

Not unexpectedly, the experimental DFTs deployed in our study functioned as fish aggregating devices within days of deployment, providing shelter and habitat for hundreds of juvenile fish and macro-invertebrates; similar attraction has been observed in Puerto Rico (R. Hill- unpublished data). The fish attraction function was particularly enhanced in areas of low structural complexity, such as seagrass beds and sand habitats in shallow water nearshore locations. During most surveys of traps over seagrass, as many as 100 to 450 juvenile fish were observed schooling in mixed

species groups within 1 m of the traps. Species included ecologically and economically important species such as tomtates (*H. aurolineatum*); French grunts (*H. flavolineatum*); bluestriped grunts (*H. sciurus*); yellowtail snapper (*O. chrysurus*); yellow (*Mulloidichthys martinicus*) and spotted goatfish (*P. maculatus*). During the passage of Hurricane Earl, the seagrass traps were lost and subsequently the juvenile fish populations diminished in that area. Derelict traps also functioned as artificial patch reefs for coral and gorgonian communities as many species were documented growing on the traps (G. Renchen-unpublished data).

Damage to sensitive habitats such as coral reefs and seagrass beds is often assumed with derelict fishing gear due to gear movement and entanglement, although existing studies have focused primarily on nets and fishing line (Matsuoka et al. 2005; Pawson 2003). In the U.S. Virgin Islands, we demonstrated that hurricane storm conditions are capable of moving DFTs over large distances, presumably through a rolling motion through high wave action. Shallow traps moved considerably farther than deeper traps suggesting that traps in deeper water are less affected by wave energy and are more stable. This is confirmed by sightings of heavily fouled DFTs in deeper water colonized by a high diversity of coral reef organisms, including scleractinian corals and sponges (S. Pittman-pers. obs). Commercial trap fishermen set traps in a range of habitat types including algal plains, low-relief pavement and sand areas close to reef slopes. These habitat types are usually in waters deeper than 16 m, where trap movement is less likely to occur unless there is an extreme hurricane event. However, many unregistered traps are set in nearshore shallow water where they are

much more likely to be mobilized by lesser storms or major swell events, and therefore more likely to impact sensitive habitat structure.

In conclusion, the impact of ghostfishing will be a function of trap condition, particularly the functionality of escape panels. Federal and territorial regulations in the U.S. Virgin Islands require that fishermen have at least one escape panel that is tied shut using a biodegradable rot cord made of untreated jute twine with a diameter no larger than 1/8 in. (U.S.V.I D.P.N.R. 2009); however compliance with these regulations and the life span of the rot cord and other commonly used materials may need to be further investigated. Despite relatively low levels of mortality documented in this study, mitigation through trap disposal programs would reduce the occurrence of DFTs and their capability to ghostfish. Disposal of old traps at sea is common practice in Caribbean trap fisheries and preliminary surveys off St Thomas and St John with autonomous underwater vehicles has revealed several test areas with higher than expected DFT densities (NOAA Biogeography Branch, unpublished data). With a trap population of approximately 8,000 units for the St. Thomas-St. John fishery and an estimated trap life of five years for commercial fishing (W. Ledee -pers. comm.) disposal of all traps at sea would result in an accumulation of approximately 32,000 traps on the seafloor over a 20 year period. This estimate, however, has obvious uncertainty due to a lack of reliable data on trap use, dereliction rates and disposal behavior and limited data on the quantity of unregistered traps in the U.S. Virgin Islands fishery.

Simple modifications to fishing practices, gear design and the implementation of a trap disposal program should be examined and evaluated by both the fishing

community and supported by marine management agencies. Introduction of escape gaps to fish traps have been documented as decreasing bycatch by up to 80 percent (Johnson 2010) and could further reduce the impact of ghostfishing, particularly on species with short, laterally compressed body shapes, such as surgeonfishes, by derelict traps. Before implementing derelict trap removal programs, managers must determine the true overall impact of the traps. Those situated in deeper water and covered with diverse sessile reef organisms are less likely to move and removal may result in a greater impact to seafloor structure. Compliance with both territorial and federal regulations, use of a proper biodegradable rot cord for escape panels, as well as disposal of disused traps on land instead of at sea could potentially reduce mortality from ghostfishing and help reduce marine debris. Due to the variability in derelict trap condition and fish behavior, the association between DFTs and ghostfishing should be considered carefully when extrapolating the economic and ecological impacts of derelict traps.

[1] Based on information gathered from Lia Ortiz, Fisheries Historical Ethnoecology Project http://fisheries.mindscribble.net/home

[2] Chairman, St. Thomas, USVI Trap Reduction Committee

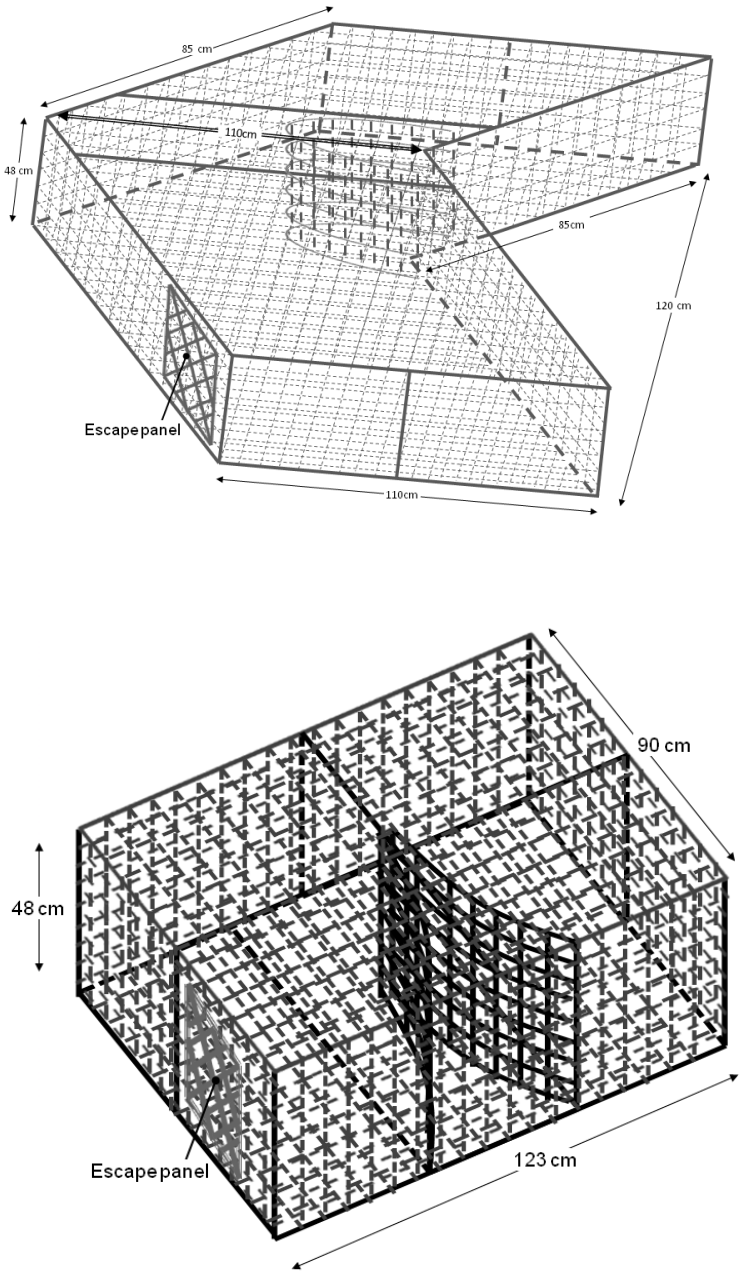


Figure 2.3.1. Diagrams of the chevron or arrowhead and rectangular traps used in the experimental derelict trap study. Illustrations created by Chris Jeffrey, NOAA Biogeography Branch, 2011.

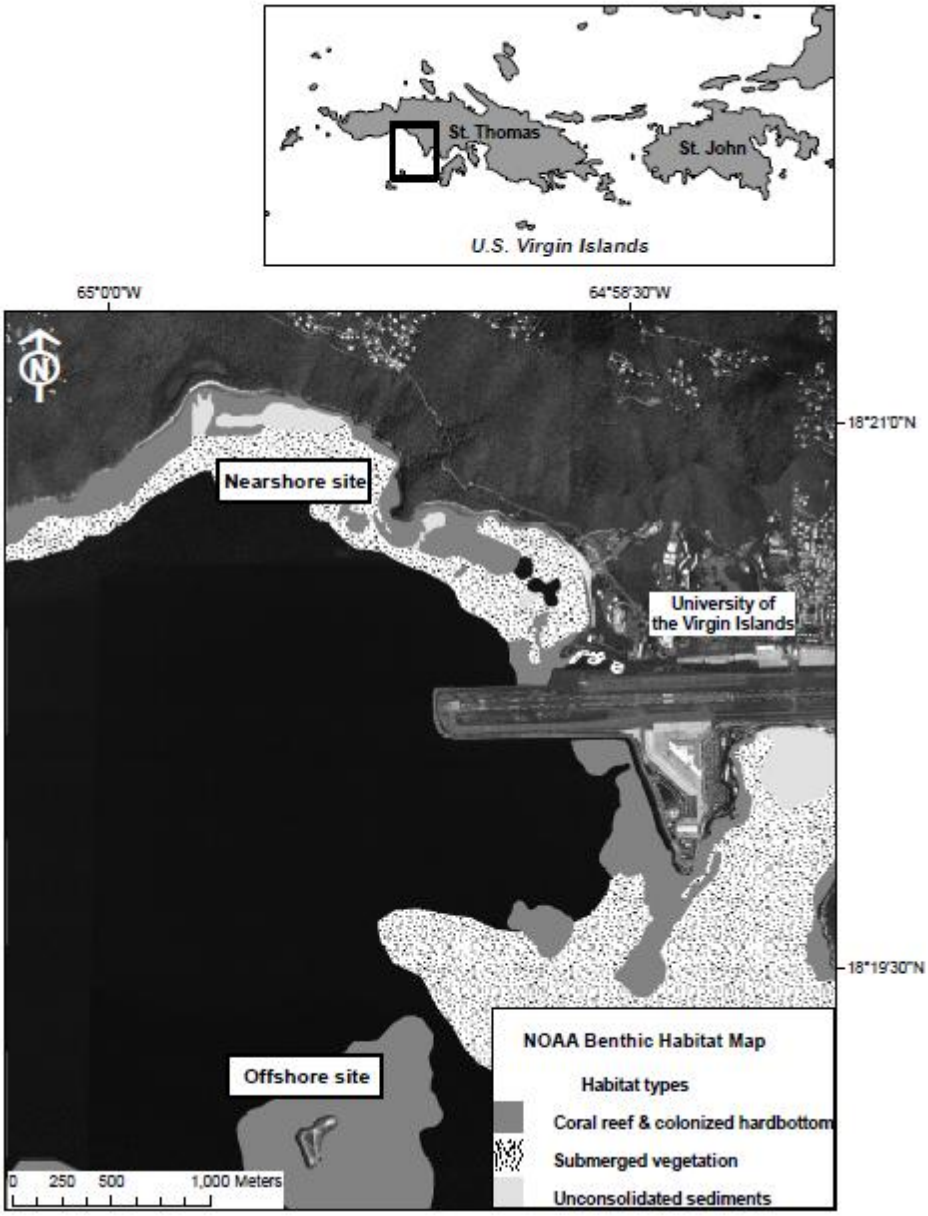


Figure 2.3.2. Map of the study area on the southwest shore of St. Thomas, U.S. Virgin Islands showing nearshore and offshore trap locations. The distribution of benthic habitat types is depicted by NOAA's benthic habitat map.

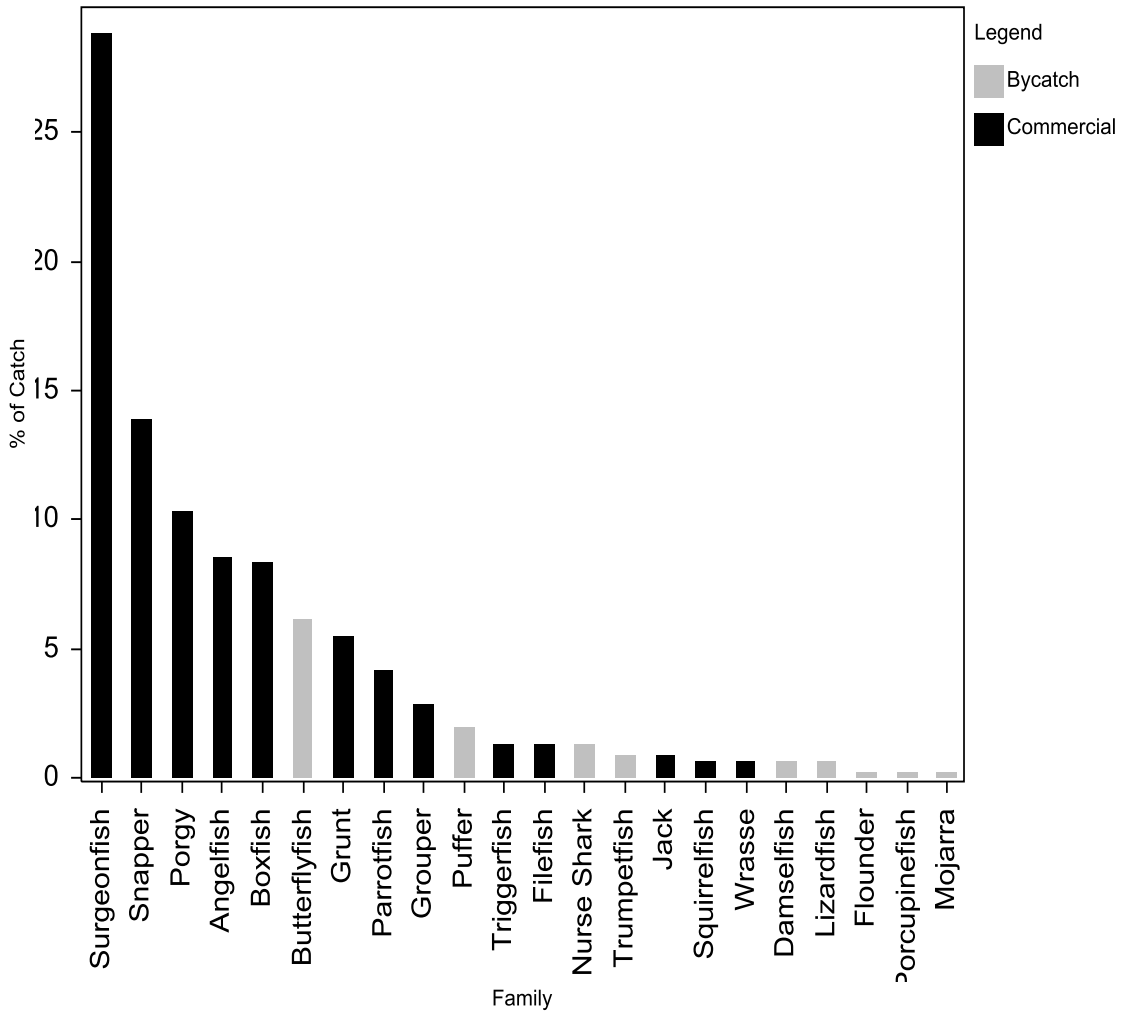


Figure 2.3.3. Proportion of the total catch in experimental derelict fish traps grouped by fish family for a six month study period on the south shore of St. Thomas, U.S. Virgin Islands.

Table 2.3.1. Summary information for the experimental derelict traps. Subscripts indicate open (o) and closed (c) traps.

Trap	GPS Coordinates	Location	Habitat	Total # fish caught	# Fish that Lived	Proportion of Mortality (Mort/total # fish caught)	Biomass of Fish Caught (lbs)	Biomass of Mortality (lbs)
1_c	N 18.31864 W 64.99024	Flat Cay	Coral/Near-Reef	105	103	0.028	81.2	6.58
2_c	N18.31869 W 64.99023	Flat Cay	Coral/Near-Reef	101	100	0.010	51.9	4.31
3_o	N 18.31871 W064.99002	Flat Cay	Coral/Near-Reef	0	0	0	0	0
4_o	N 18.31825 W 64.98981	Flat Cay	Sand/Far-reef	0	0	0	0	0
5_c	N 18.31827 W064.98965	Flat Cay	Sand/Far-reef	66	63	0.045	54.5	1.76
6_o	N 18.31825 W 64.98969	Flat Cay	Sand/Far-reef	0	0	0	0	0
7_o	N 18.34960 W064.99310	Perseverance Bay	Coral/Near-Reef	0	0	0	0	0
8_c	N 18.34953 W 64.99306	Perseverance Bay	Coral/Near-Reef	46	44	0.043	46.3	15.2
9_c	N 18.34957 W 64.99025	Perseverance Bay	Coral/Near-Reef	53	50	0.057	52.7	16.5
10_o	N 18.34826 W 64.98718	Perseverance Bay	Sand/Far-reef	0	0	0	0	0
11_o	N 18.34818 W 64.98724	Perseverance Bay	Sand/Far-reef	1	0	1.00	0.96	0.96
12_c	N 18.34817 W 64.98715	Perseverance Bay	Sand/Far-reef	82	75	0.090	89.9	6.06

Table 2.3.2. Fish mortality in the experimental derelict fish traps during the six month ghostfishing study. ** Species considered by fishermen as potentially unmarketable due to risk of ciguatera poisoning in the U.S. Virgin Islands.

Family	Species	# Mortalities	Mortality Ratio (# mortalities/total #caught)	% of Mortalities with Injuries	Mean Biomass (lbs)	Market Price** ($/lb)
Ostraciidae	*Acanthostracion quadricornis*	1	0.25	-	0.67	3
Monacanthidae	*Aluterus scriptus*	2	1.0	50	0.63	Bycatch
Sparidae	*Calamus calamus*	6	0.13	16	0.90	5
Serranidae	*Epinephelus guttatus*	1	0.10	100	0.51	6
Rhincodontidae	*Ginglymostoma cirratum*	1	0.33	-	10.4	Bycatch
Ostraciidae	*Latophrys triqueter*	2	0.06	-	0.29	3
Lutjanidae	*Lutjanus apodus*	1	0.03	100	0.48	Bycatch**
Lutjanidae	*Lutjanus jocu*	2	0.67	50	5.34	Bycatch**
Lutjanidae	*Ocyurus chrysurus*	2	0.25	100	10.2	6
Pomacanthidae	*Pomacanthus arcuatus*	1	0.03	-	0.09	6
Sphyraenidae	*Sphyraena barracuda*	1	1.0	100	0.96	Bycatch**

Table 2.3.3. Fish behavior by fish family observed during the ghostfishing study. Behaviors are expressed as a percentage of the total number of individuals per family exhibiting the behavior. Behavior abbreviations are as follows: IATE=individual attempting to escape; SCATE= school of fish attempting to escape; AGG=aggregating; SC=schooling, not trying to escape; ISW=individual swimming, not trying to escape; C=calm, stationary; AV=avoiding others; AGR= aggression

Family	IATE	SCATE	AGG	SC	ISW	C	AV	AGR
Acanthuridae	22.9	65.6	3.1	6.1	0.8	1.5	-	-
Aulostomidae	-	-	-	-	50.0	50.0	-	-
Balistidae	50.0	33.3	-	-	-	16.7	-	-
Bothidae	-	-	-	-	-	100.0	-	-
Carangidae	100.0	-	-	-	-	-	-	-
Chaetodontidae	32.1	67.9	-	-	-	-	-	-
Diodontidae	100.0	-	-	-	-	-	-	-
Gerreidae	-	-	-	-	-	-	100.0	-
Haemulidae	20.0	-	60.0	-	-	20.0	-	-
Holocentridae	-	-	-	-	-	100	-	-
Labridae	66.7	-	-	-	-	33.3	-	-
Lutjanidae	3.2	15.9	38.1		20.6	1.6	20.6	-
Monacanthidae	-	-	-	-	33.3	66.7	-	-
Ostraciidae	68.4	31.6	-	-	-	-	-	-
Pomacanthidae	69.2	25.6	-	-	-	-	-	5.2
Pomacentridae	-	-	-	-	-	-	100.0	-
Rhincodontidae	-	-	66.7	-	-	33.3	-	-
Scaridae	36.8	10.5	31.6	-	-	21.1	-	-
Serranidae	30.7	-	7.7	-	-	38.8	23.1	-
Sparidae	19.1	-	63.8	-	-	-	17.1	-
Synodontidae	-	-	-	-	-	-	100.0	-
Tetraodontidae	-	-	-	-	88.9	11.1	-	-

CHAPTER 3: UNDERWATER VIDEO ANALYSIS OF FISH BEHAVIOR IN EXPERIMENTAL DERELICT FISH TRAPS

Gabrielle F. Renchen, Simon J. Pittman and Marilyn E. Brandt

Journal of Fish Biology
http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1095-8649/issues
To be submitted

3.1 INTRODUCTION

Fish traps are an economically important gear used throughout the Caribbean to catch a variety of reef fish and crustaceans. Studies have been done assessing the mode of operation and selectivity of fish traps (Munro et al. 1971; Gobert 1998), as well as their impacts on coral reef ecosystems and fisheries (Sheridan et al. 2006; more refs); however very little research has been conducted on the actual behavior of fish in response to fish traps. The behavioral responses of fish to traps will provide ecologically relevant information that can be used to effectively manage and sustainably enhance trap fisheries.

Underwater diver observations of fish in traps collected by Luckhurst and Ward (1987) indicated that fish captured do not behave normally and were recorded repeatedly butting into mesh and injuring themselves. While diver observations can provide insightful data, the operations can be expensive, often time limited and may produce inaccurate, biased behavioral results (Jury et al. 2001). Direct, unbiased observations of fish behavior, abundance and habitat use have been successfully obtained through the use of underwater video techniques (Barnes 1963; Jury 2001; Pratt et al. 2005). Underwater video samples are non-extractive, unobtrusive and recordings can be used repeatedly to collect a wide array of data such as species behavior and interactions, time comparisons, fish abundance and size etc. (Cappo et al. 2006).

Through the use of underwater video techniques, unbiased observations of fish behavior in relation to fish traps can supply scientists, fishermen and resource managers with reliable information to more fully understand the behavioral processes involved in trapping fish and to design gear to minimize impacts to maintain an efficient and sustainable fishery. Overfishing has been a concern in the Caribbean and globally for many years thus prompting managers to evaluate their fisheries and management regimes (Jackson et al. 2001; Hughes 1994). Attempts to modify gears or improve management efforts may prove difficult if there is not a sufficient knowledge base and understanding of the behavioral responses of fish to the gear (Bardach 1980).

In the U.S. Virgin Islands, fish traps are the most commonly used fishing gear on the islands of St. Thomas and St. John. The size of the fishery is equivalent to small scale commercial, with all profits staying on the islands. The chevron or arrowhead and rectangular traps are the most commonly used trap designs. Work has been done investigating bycatch (Olsen 2008) and also the impacts of ghostfishing from derelict fish traps (Renchen et al. in review), however behavioral observations have been limited (e.g. High and Beardsley 1970). The overarching goal of this study was to determine how fish respond to fish traps and how fish traps function as part of a coral reef ecosystem. From a fishermen's perspective, understanding why certain fish are prone to damage could affect the marketability and price of species while diurnal and nocturnal activity patterns and entry and exit times will further the understanding of trap selectivity and the design of lower impact traps (i.e. position of escape vents). The susceptibility to capture, interactions between species, energetics and relationships between size and behavior of trapped fish are all ecologically relevant trap-fauna

relationships that need to be considered for effective management. Specific objectives of this study were to determine how fish behave in the trap (are they antagonistic, avoid one another, aggregate, damage themselves etc.), how fish allocate their time in traps (what proportion of their time is allocated towards attempting to escape, grazing etc.) and if a temporal pattern exists in the entering and exiting of fish in the traps. Specific hypotheses evaluated were:

H_1: Fish have a temporal pattern of capture and escape

H_2: The proportion of time allocated to different behaviors will be significantly different between fish species

3.2 MATERIALS AND METHODS

Trap Cam System

We used a custom-built underwater video surveillance system, referred to as TrapCam, which consisted of a 540TV line resolution bullet camera with an automatic switch from color to black and white video under low-light conditions (.05 lux, 4 mm lens, Model 214157-01, Bellamare Subaquatic Services and Technologies, La Jolla, CA). To continuously record in high resolution for 24 hours required a separate DVR (Digital Video Recorder) powered by a 12V, 20ah Nimh battery. Video files were stored in four hour segments on a 32 GB compact memory card (ScanDisk) . The entire system was mounted in a PVC underwater housing rated to 130 feet in depth.

The TrapCam was made negatively buoyant with lead weights and mounted on the seafloor on a concrete block 1m from the entrance funnel of the fish trap. Two

Princeton Tec Shockwave LED underwater dive lights that provided a maximum of 20 hours of light were attached to stakes and mounted at the two opposing rear corners of the trap, with beams aimed at the entrance funnel. The lights were covered with a magenta colored filter (Rosculux #46 Magenta, 6% transmission, Rosco Laboratories, Stamford, Connecticut) to decrease the influence of the light on fish behavior. Observations revealed that no fish were attracted to the red lights.

Study Sites and Field Sampling

TrapCam deployments (n=15) were conducted at Range Cay (N18.339444 W64.978451), a shallow inshore hard bottom area with scattered coral communities, in St. Thomas, U.S. Virgin Islands. Traps were deployed at a depth of approximately 5 m deep and is an area that is fished by local subsistence and recreational fishermen. The TrapCam system was deployed between the hours of 1500-1600 and retrieved at the same time 24 hours later. This time frame was used to ensure that the lights functioned long enough to aid in the capture of night time entrances and exits. A total of 15, 24 hour samples were collected totaling 326.3 hours of footage.

Video Analysis

Video samples were analyzed for fish entry and exit times, activity periods and behavioral interactions of fish both inside and outside the traps. The start and end time of fish activity periods were recorded and used to determine what proportion of an entrapped fish's time was allocated towards particular activities during the daylight hours only. Start and end times were recorded when a significant change in activity occurred; the ability to rewind the footage allowed us to verify the timing of the activities. Identified fish behaviors were classified into 14 categories for those caught

inside the trap and 13 categories for those outside the trap (Tables 3.3.1 and 3.3.2). In an effort to not inflate the catch information, fish observed entering and exiting multiple times were only counted once for the total catch. In addition, to examine the frequency of occurrence for any particular activity type, counts were made of the number of times a behavioral interaction occurred. For instance, if a fish displayed aggression towards another species this was documented as a count rather than an amount of time. Fish that approached the traps or were visible within one meter of the traps were also recorded. Due to a narrow beam width, night-time video was unable to discern behavior within the trap beyond the entrance funnel; therefore night observations were limited to recording of entry and exit times only. Sizes of trapped fish were estimated using the scale (i.e. 2 inch mesh) of the trap mesh as a guide.

Data Analyses

The five most frequently observed distinct behaviors were identified and used in the analyses: 1) entering and exiting, 2) grazing, an individual attempting to escape, 3) aggregating with other fish and attempting to escape and 5) staying in one place. The amount of time species allocated to each behavior was converted into a proportion and analyzed for differences between species using the multivariate ordination technique non-metric multidimensional scaling (nMDS). Statistical tests of differences among species were also performed by applying the technique, Analysis of Similarities (ANOSIM), a multivariate analogue of ANOVA developed by Clarke and Warwick (2001). Only species where four or more individuals were assessed for behavior were included in the analyses. All analyses were performed in the statistical software program PRIMER v. 6 (Primer-E Ltd).

3.3 RESULTS

Catch composition

In the 326.3 hours of footage collected, a total of 100 fish were identified within traps comprising 12 families and 18 species (Figure 4). The most frequently observed families were: surgeonfish (*Acanthuridae*, n=29 individuals), snapper (*Lutjanidae*, n=20), boxfish (*Ostraciidae*, n=15), angelfish (*Pomacanthidae*, n=8) and porgy (*Sparidae*, n=8). The most frequently observed species were: doctorfish (*Acanthurus chirurgus*, n=28 individuals), smooth trunkfish (*Lactophrys triqueter*, n=16), yellowtail snapper (*Ocyurus chrysurus*, n=11), saucereye porgy (*Calamus calamus*, n=8) and gray angelfish (*Pomacanthus arcuatus*, n=7). The minimum and maximum total lengths (TL) recorded for trapped fish were 12 cm and 100 cm respectively, with a mean size of 25.2cm ± 1.8cm. The smallest individuals caught were a striped butterflyfish (*Chaetodon striatus*, 12 cm TL) and smooth trunkfish (*L. triqueter*, 12 cm TL) and the largest was a nurse shark (*Ginglymostoma cirratum*, 100 cm TL).

Fish behavior

A wide variety of fish behavioral interactions were observed in the video samples with 13 behaviors expressed among individual species and families. The proportion of time allocated to the top five behaviors was not significantly different

between fish species (ANOSIM R=0.04, p=0.21) (Table 3.3.3). The nMDS ordination plot revealed high overlap in the behaviors exhibited by species, with no clear separation; however it did provided a good two-dimensional representation of the multivariate behavioral data as indicated by a low stress value of (0.07).

Overall, combined across all samples, 45% percent of the behavior observed was comprised of an individual fish attempting to escape, while 30% was comprised of multiple fish schooling in one area of the trap and trying to escape. The behavior of attempting to escape was characterized by fish swimming throughout the trap or aggregating in one area of the trap and typically banging into the mesh. Fish were often observed attempting to escape at the corners of the trap. Species most often observed banging into the mesh included *O. chrysurus*, *C. calamus* and *L. triqueter*. The remaining most frequently used behaviors, staying stationary in one area, grazing and entering and exiting were observed 11.8%, 8.9% and 1.2 % of the time respectively. Less frequently observed behaviors included attempting to escape while schooling throughout the trap (1.13% of the time), attempting to escape while avoiding others (0.56%), biting at the mesh (0.26%), picking at dead fish remains (0.08%), swimming not attempting to escape (0.04%), staying in one area while avoiding others (0.04% and fish from the outside entering the trap to pick at dead fish remains (0.004%). Two rather unusual behaviors were also observed in addition to the less frequently observed behaviors; a nurse shark rolling on its back, presumably to scratch off parasites and a spotted burrfish (*Chilomycterus atinga*) puffing up in response to a large predator (Cubera snapper, *Lutjanus cyanopterus*) circling the trap.

Fish were also observed entering and exiting (escaping) the trap through the entrance funnel. A total of 167 entrances and 173 exits were recorded. There were more entrances and exits than the total number of fish caught because several of the fish transiting into and out from the trap were the same individuals observed on multiple occasions. Trap entrances and exits were highest at the hours of 5am, 8am and 12pm (Figure 5) and decreased after 1 pm. A total of 10 species were observed exiting the trap with doctorfish (*A. chirurgus*) comprising approximately 67% of the escapes (Figure 6).

Species outside the trap

A total of 1,585 fish were observed within 1 meter of the outside of the trap over the course of the 15 video samples. The striped parrotfish (*Scarus iserti*) was most abundant, accounting for over half (54.4%) of the species observed outside the trap. The doctorfish (*A. chirurgus*), sharpnose puffer (*Canthigaster rostrata*), juvenile yellowtail snapper (*O. chrysurus*) and princess parrotfish (*S. taeniopterus*) comprised the remainder of the top five species. Species outside the trap were mostly observed grazing on the trap or using it as shelter, darting in and out of the trap mesh.

A total of 13 behaviors or activities were observed for fish outside of the trap. Approximately 73% of fish were observed grazing on the trap. Grazing intensity (# grazers per hour) steadily increased until 10 am, dropped off at 11 am and then slowly decreased from 12 pm until sunset (Figure 7). The remaining top behaviors exhibited were darting in and out of the trap mesh (13.3% of fish), swimming over the trap (4.7%), entering through the trap mesh to pick at dead fish remains (2.5%) and approaching the trap entrance funnel (1.8%).

A total of 28 fish outside were observed approaching the trap entrance funnel when other fish were inside. Eighteen percent of the approaches resulted in entrapment. The presence of fish inside the trap appeared to attract other fish to the trap, often those of the same species. Approximately 67% of the fish that approached the trap entrance funnel were conspecifics of those already trapped. Seven fish outside the traps were observed swimming alongside a conspecific on the inside of the trap. Species exhibiting conspecific attraction were *A. chirurgus*, *L. triqueter*, *C. atinga*, *P. arcuatus*, and *C. calamus.*

Attraction of predators to the trap was also observed. Six species of predatory fish were observed including the cubera (*L. cyanopterus*, n=17), barracuda (*Sphyraena barracuda*, n=11), tarpon (*Megalops atlanticu*s, n=7), crevalle jack (*Caranx hippos*, n=5), bar jack (*C. ruber*, n=2) and horse eye jack (*C. latus*, n=2). Of the predatory fish observed, three species (cubera, crevalle jacks and barracuda) attempted to enter the traps or reach fish through the mesh. The cubera was observed circling the trap on several occasions, while three crevalle jacks were observed on one occasion both of which caused fish inside the trap to display a frightened behavior and move to the opposite side of the trap. The other fish were observed frequently swimming over the top of the trap or directly in front of the camera and trap entrance.

3.4 DISCUSSION

Due to the passive nature of fish traps, catch is dependent upon fish actually encountering the gear and their vulnerability to the gear (i.e. entering and not being

able to escape) (Stoner 2004; Robichaud et al. 2000). Studies have suggested that factors such as traps providing structure, and the presence of predators and prey can also influence whether fish enter traps (High and Beardsly 1970; Matthews 1985; Renchen-unpublished data), but the underlying behavioral characteristics of the fish may influence whether fish enter, remain or escape from traps.

Fish were observed expressing multiple behaviors while trapped; however, unexpectedly there was high overlap in the proportion of time species allocated to these behaviors as indicated by the nMDS and non-significant ANOSIM. A mixture of coral reef associated species were caught that included diurnal and nocturnal species, as well as herbivores and piscivores. Under free-swimming, untrapped conditions, differences and distinct patterns in the behavior of fish with these characteristics have been documented (Helfman 1993). Physical disturbances, such as capture in a trap, may however disrupt or alter the normal behavioral and movement patterns, leading to a state of physical and neurological distress (David and Closs 2001) that could induce an overlap in behaviors and lead to similar behavioral outcomes for all species.

Most fishing techniques induce stress responses in fish due to the high amount of energy exerted and subsequent fatigue caused by attempting to escape (Skomal 2007). Stress responses are a mechanism that enables fish to avoid or prevail in threatening conditions (Chopin and Arimoto 1995; Chopin et al. 1996). Although stress was not directly measured in this study, capture and confinement has been documented as increasing the stress levels in fish (Hopkins and Cech 1992) and can be quantified by monitoring changes in blood chemistry such as plasma cortisol levels (Skomal 2007; Chopin et al. 1996; Barry et al. 1993). Stress responses can be very

costly by detracting fish from other behaviors such as feeding and also result in large amount of energy expenditure (Brown et al. 2003). Fish expending large amounts of energy attempting to escape could potentially lead to starvation depending on several factors such as the amount of food in the stomach when caught, and the metabolic debt and rate of oxygen consumption (Stoner 2004; Weber and Haman 1996).

Related to stress responses are the alarm responses or chemical cues emitted by fish after being attacked by a predator or suffering skin damage. Fish may or may not respond to alarm responses for a number of reasons but fish that are confined in a small area or are wary of becoming trapped may react more strongly to the alarm response (Magurran et al. 1996). For example, a species caught in traps that is injured (e.g. scrapes from attempting to escape) and stressed may emit an alarm response that another trapped species may detect in addition to its physical movements, thus causing multiple species to become wary and attempt to escape or exhibit a similar behavior. Alarm responses could also make un-trapped fish wary of coming near the trap, potentially influencing the catch.

Although there was not a significant difference in the amount of time species allocated to different behaviors it may be possible to generally, but cautiously infer which species were more stressed than others. For example species such as the yellowtail snapper, smooth trunkfish, spotted burrfish and red band parrotfish all spent the largest proportion of their time attempting to escape and were often observed banging into the trap mesh. These species may therefore be more stressed than species such as doctorfish that spent the majority of their time grazing. Further evidence of species specific levels of stress can be inferred from Renchen et al. (in review) which

observed bodily damage on two of the same species (yellowtail snapper, smooth trunkfish) and one of the same family (*Scaridae*) observed butting in the mesh in this study.

Multiple fish of the same species, or conspecifics, were often observed both inside and outside the traps and in many cases conspecific approaches resulted in entrapment. Evidence of conspecific attraction has been extensively examined (Luckhurst and Ward 1987; Munro 1974; Munro et al. 1971) but the underlying mechanisms are not as well documented. Visual cues such as fish shape and color have been documented as important factors utilized by fish for conspecific attraction and also aggression (Blaxter 1980; Keenlyside 1955). Recently however, Ward et al. (2002) has suggested that chemical cues may be more important than visual cues as they enable fish to identify conspecifics from heterospecifics with a high degree of specificity and thus influence social behavior. Research on sound detection and auditory cues in fish suggests that sound is an important mechanism in which fish can detect the location of conspecifics and heterospecifics (Popper and Lu 2000). All of these sensory cues likely influence the behavior of fish inside and outside the trap perhaps contributing the behavioral overlap and attraction of both conspecifics and predators such as the cubera and crevalle jacks.

Entrances and escapes of fish appeared to peak in the morning and then taper off after 1200. This may be attributed to the diurnal and nocturnal activity patterns exhibited by fish. Although behavior from the night-time footage was not analyzed due to the inability to light the entire trap, nocturnal species such as snappers, jacks and nurse sharks could be seen actively passing through the trap at night. In contrast,

diurnal species such as the doctorfish were repeatedly observed entering and exiting the trap during the daylight hours only. The behavior of doctorfish documented in this study further explains the results of Renchen et al. (in review) which also documented doctorfish as comprising the largest percentage of the catch, yet had no recorded mortalities. Behavioral activity of fish may also determine which species escape or enter the traps. More mobile species such as surgeonfish that are accustomed to navigating reefs may be more likely to encounter a trap, but because they are very active they may also be more likely to find the exit (Robichaud 2000). Less mobile species such as the nurse shark which allocated the majority of their time to sitting in one place may be less likely to find the exit simply because they are not moving through the trap.

The results of fish behavior and escapement obtained from this study are relevant to the use of escape gaps as an approach to managing multi-species trap fisheries in the Caribbean. As most fish attempted to escape at the corners, the footage can be used to identify potential escape gap placements and then further determine the appropriate sizes. Escape gaps have been documented as reducing bycatch by up to 80% (Johnson 2010) and indicate that proper size and placement can be effective at releasing undersized species without significantly decreasing the catch (Munro et al. 2003). A collaborative study between the National Marine Fisheries Service and the St. Thomas Fishermen's Association is currently underway to determine the feasibility of escape gaps as a management tool for the U.S. Virgin Islands trap fishery.

A successful sustainable fishery is dependent upon not only the function of the gear, but also the basic knowledge of the behavior of the fish being caught. With the

increase in the availability of low-cost video equipment, scientists, fishermen and managers can gain a greater scientific understanding of how fish are affected by fishing gear and also how the gear functions as part of an ecosystem, particularly with passive gears such as traps. The behavioral observations obtained from this study have provided insight into the efficiency of fish traps, the condition fish may be in after being caught and how they function as part of a coral reef ecosystem. The results indicate which species may be more vulnerable to capture and mortality while entry and escape information can be related to the catch per unit effort obtained by local fishermen and the placement of escape gaps.

Table 3.3.1. The distinct, identifiable fish behaviors observed from species caught inside the trap.

Inside Trap		
Behavior	**Abbreviation**	**Example**
Entering and exiting	EE	Surgeonfish entering and exiting entrance funnel
Grazing	G	Surgeonfish grazing on algae growing on trap
Individual attempting to escape	IATE	One fish attempting to escape
Schooling, attempting to escape	SCATE	Multiple species of fish schooling in one area of the trap, attempting to escape
Schooling, scanning, attempting to escape	SSCATE	Surgeonfish schooling, swimming throughout the trap, attempting to escape
Staying in one place	SIOP	Nurse shark sitting in one spot, not moving throughout trap
Staying in one place, avoiding others	SIOPAO	Schoolmaster staying in one place on opposite side of trap from other fish
Avoiding others, attempting to escape	AVATE	Schoolmaster attempting to escape on opposite side of trap from other fish
Swimming, not attempting to escape	SNATE	Trunkfish swimming throughout trap without touching mesh or attempting to escape
Biting at mesh	B	Angelfish biting at mesh
Picking at carcass	PAC	Fish caught in trap, picking at dead fish carcass
Entering and picking at carcass	EPAC	Surgeonfish entering trap, picking at dead fish carcass
Rolling on back	R	Nurse shark rolling on its back, rubbing on trap floor
Puffing up	P	Balloonfish puffing up in response to predators outside

Table 3.3.2. The distinct, identifiable fish behaviors observed from species observed outside the trap.

Outside Trap		
Behavior	**Abbreviation**	**Example**
Grazing	G	Surgeonfish grazing on algae growing on trap
Darting in and out	DD	Juvenile yellowtail snapper darting in and out of mesh
Swimming by	SB	Barracuda swimming by trap within 1 m of trap
Picking at carcass	PAC	Wrasse entering through mesh to pick at fish carcass
Approached funnel	APF	Fish approaching entrance funnel, not entering
Darting in and out of light	DDL	Juvenile lane snapper darting in and out of light beam at night
Attracted to stirred up sediment	ATS	Juvenile yellowtail snapper swimming to trap in response to stirred up sediment
Approached camera	AC	Squirrelfish swimming up to camera housing
Attacking camera	ATC	Juvenile french grunt displaying aggression, attacking camera housing
Circling trap	CT	Cubera snapper swimming around trap
Attracted to conspecific inside	ACI	Trunkfish outside swimming alongside conspecific inside
Rubbing against other fish	R	Lane and yellowtail snappers rubbing against each other
Sitting in trap	SIT	Barred hamlet entering through trap mesh, sitting in one place

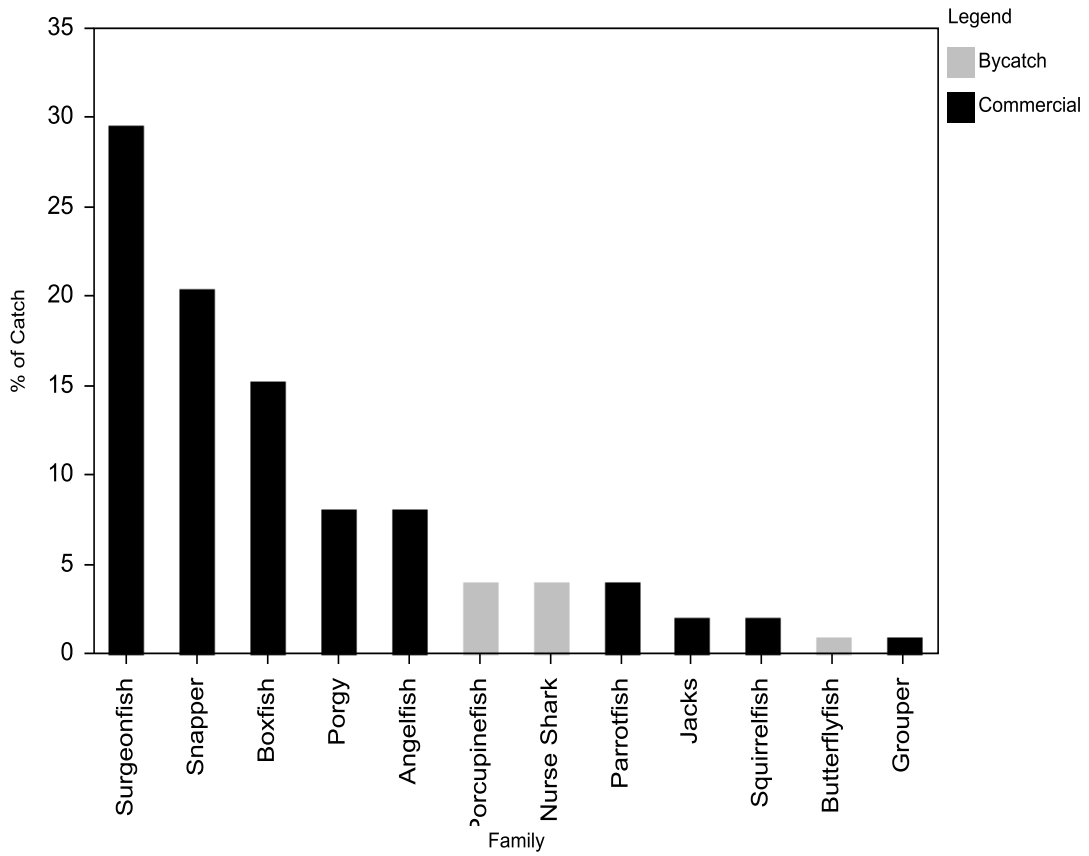


Figure 3.3.1 Proportion of the total catch grouped by fish family for all 15 video samples.

Table 3.3.3. The percent of time the top ten most abundant species spent exhibiting the five most frequently recorded behaviors. Behavior abbreviations are as follows: EE=Entering and exiting; G=Grazing; IATE=Individual attempting to escape; SIOP=Staying in one place; SCATE=Schooling; attempting to escape.

Species	**EE**	**G**	**IATE**	**SIOP**	**SCATE**	**Other**
Acanthurus chirurgus	26.5	17.6	42.9	4.3	8.33	0.37
Calamus calamus	-	-	37.3	24.2	38.5	0
Chilomycterus atinga	-	-	1.2	22.4	76.2	0.2
Ginglymostoma cirratum	-	-	42.9	56.7	-	0.4
Lactophrys triqueter	0.03	11.9	66.3	1.53	19.8	0.44
Lutjanus apodus	-	-	80.6	2.70	16.7	0
Lutjanus synagris	-	-	68.1	28.3	-	3.6
Ocyurus chrysurus	-	-	50.1	1.90	45.1	2.9
Pomacanthus arcuatus	27.1	7.7	26.9	-	33.3	5.0
Sparisoma aurofrenatum	0.27	0.05	95.9	3.70	-	0.08

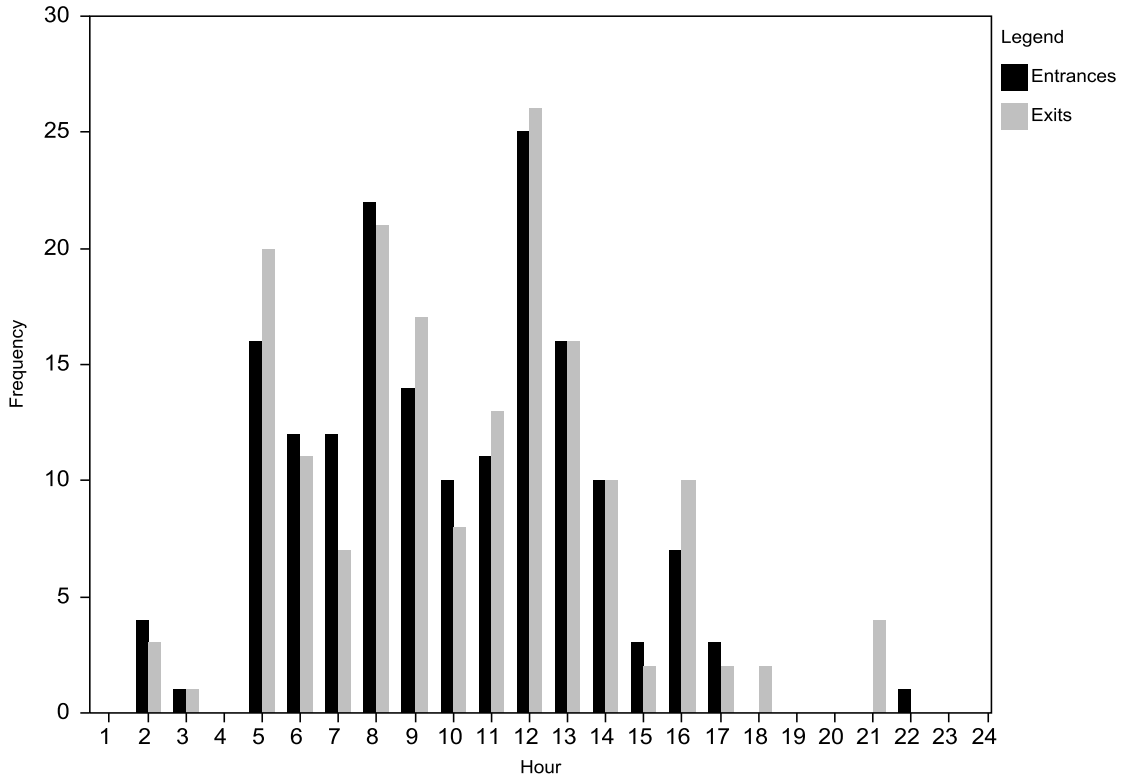


Figure 3.3.2. Frequency distribution of the number of exits and entrances recorded per hour in a day for all video samples.

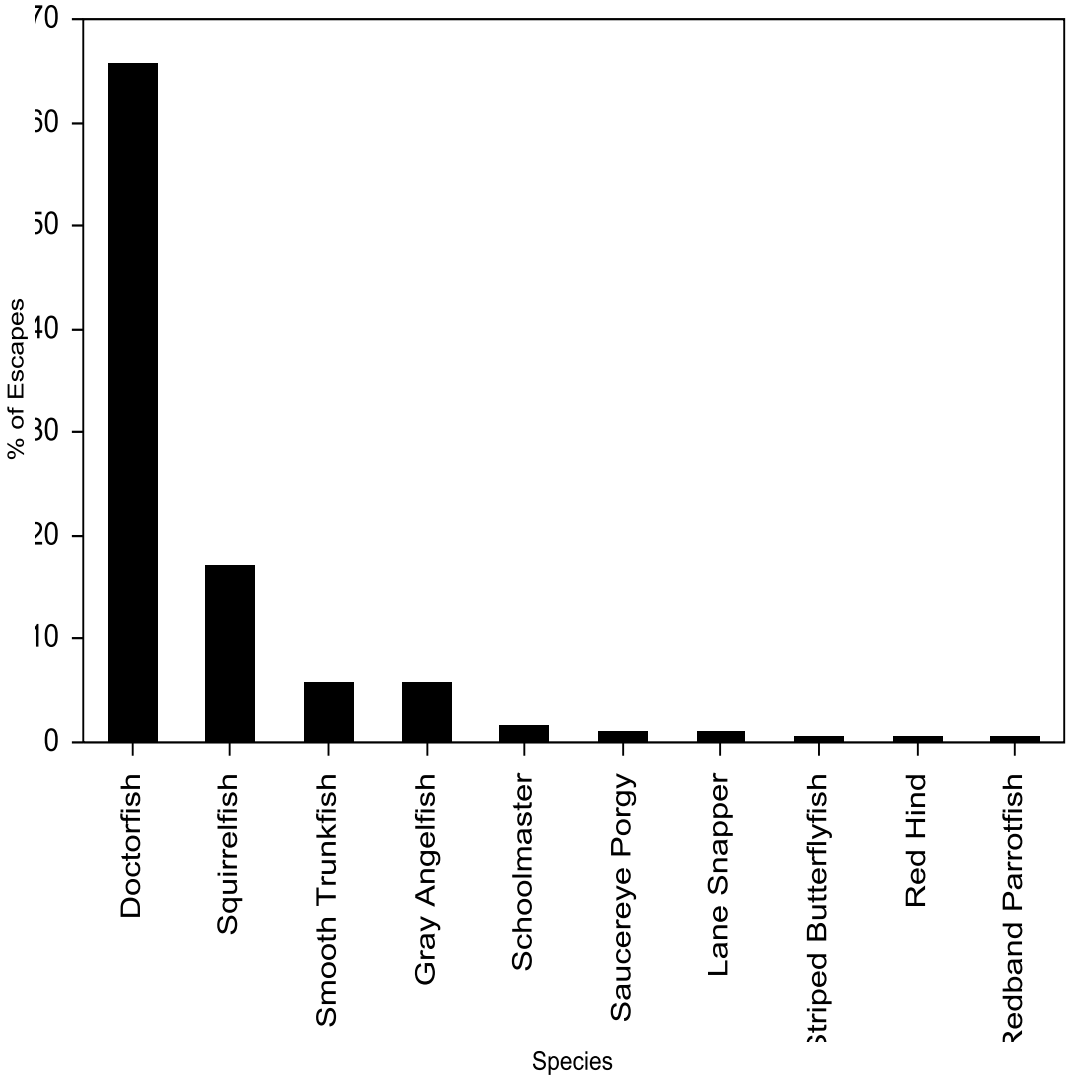


Figure 3.3.3. Proportion of individuals that escaped relative to their total catch by species. Only species observed to escape are presented.

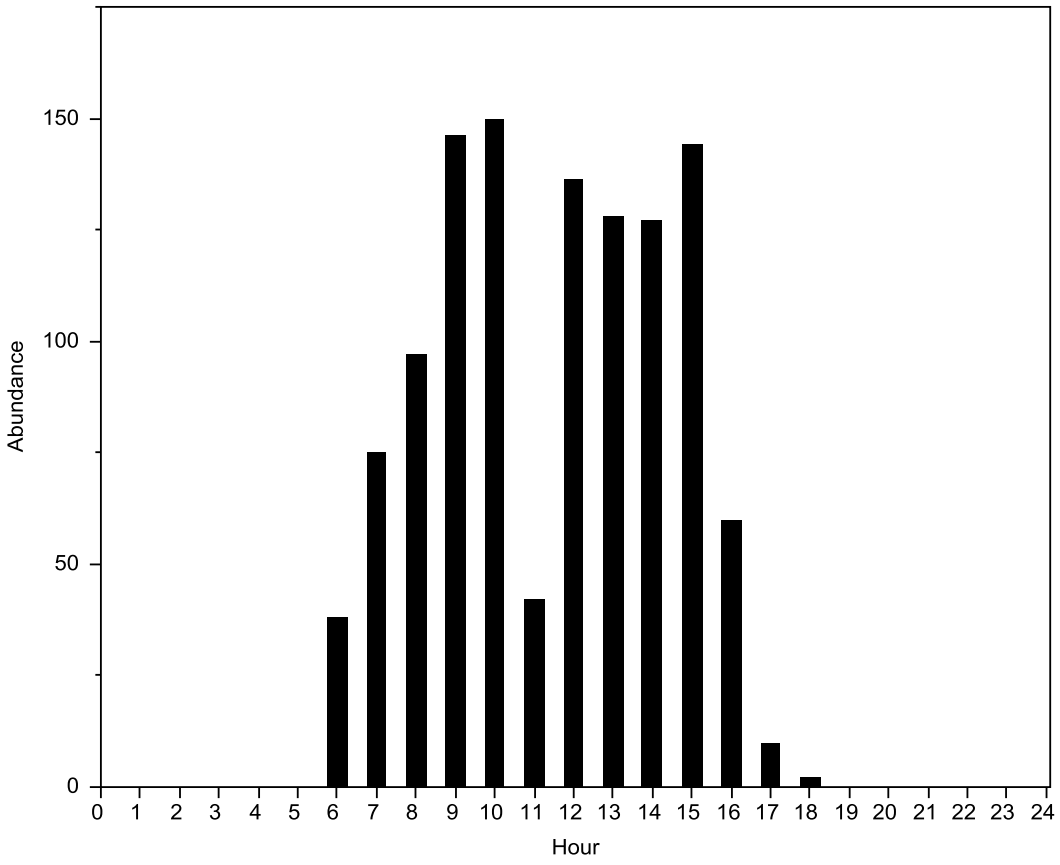


Figure 3.3.4: Grazing intensity per hour across all video samples.

CHAPTER 4: ASSESSMENT OF FOULING COMMUNITIES GROWING ON DERELICT FISH TRAPS IN THE CARIBBEAN

Gabrielle F. Renchen

Caribbean Journal of Science
http://www.caribjsci.org/
To be submitted

4.1 INTRODUCTION

Marine debris is any persistent, man-made material that has been intentionally or unintentionally disposed of in the marine environment (Stefatos et al. 1999). As the global population continues to grow and consumption of man-made materials increases, the accumulation of marine debris in the world's oceans has become a concern (Bauer et al. 2008). The types and sources of marine debris are numerous, but common items include plastics, glass, fishing gear and vessels (NOAA MDP 2011). Marine debris can pose a number of threats to both humans and marine species including navigational hazards, ghostfishing, degraded water quality, decreases in aesthetic value of marine areas and economic loss (Corbin et al. 1993). On the other hand, marine debris also creates structure in the environment, sometimes in areas where relatively little surface structure exists, thus functioning as artificial reefs, providing habitat for fauna and increasing surface area for colonizing organisms (Bohnsack 1989; Bailey-Brock 1989).

Derelict fishing gear is a common type of marine debris typically associated with areas of concentrated fishing efforts (Hess et al. 1999). Used widely throughout the Caribbean to catch finfish and crustaceans (Recksiek et al. 1991) derelict fish traps likely comprise a large portion of the submerged marine debris (Macfadyen et al. 2009). Derelict traps occur as a result of several processes including: intentional abandonment of old and damaged traps; movement of traps and or loss of trap markers from the entanglement of trap lines with boat propellers or other gears; fouling on the benthos (i.e., traps and ropes become caught on rocky substrates); human error and inclement weather (Laist 1995, Renchen et al. in review). Threats often associated

with derelict fish traps such as ghostfishing and habitat damage have been assessed (Renchen et al. 2011, Lewis et al. 2009; Marshak et al. 2007) however little information exists on the colonization of derelict fish traps and how their condition changes over time. Quantitative observations on the colonization dynamics and variability in composition of fouling communities is necessary to understand the ecological impact of derelict fish traps and other marine debris that are rarely studied. Such an understanding may also help to determine the approximate age and stability of marine debris, which can then be used to determine trends in debris accumulation and associated threats to benthic habitats from trap mobility in the marine environment.

Derelict fish traps are typically constructed of wire and rebar and therefore may persist in the marine environment for many years and are often observed overgrown by fouling organisms typically composed of sessile benthic communities. A large volume of literature exists on the development and succession of fouling communities; however most were conducted on settlement plates in temperate waters rather than tropical locations (Garcia and Salzwedel 1995). The relationship between the development of fouling communities and the length of submersion has been documented on settlement plates (Sutherland and Karlson 1977), artificial reefs (Cummings 1994), pilings (Connell 2001), etc. and recently on derelict nets (Saldanha et al. 2003), but no studies exist to our knowledge on the benthic communities associated with Caribbean fish traps.

The development of marine fouling communities is a natural process that occurs as a result of the settlement and subsequent growth of algae and invertebrates on submerged materials (Evans et al. 1981). Fouling community structure may vary

temporally and spatially in different gradients such as latitudinal, inshore to offshore or on a finer scale between habitats based on breeding times and larval transport as well as with changes in water quality (Holmes et al. 1997). The structure of fouling communities can be analyzed spatially or temporally for sequential patterns of community change, also known as seriation (Clarke et al. 1993). Breakdowns in seriation may indicate the lack of stability in fouling communities and modification by disturbances (Warwick et al. 2002; Clarke et al. 1993). The term fouling often has a negative connotation as it is typically referred to in the context where growth is considered a nuisance (e.g. fouling of ship hulls); however we use the term to refer to benthic communities or assemblages of plants and sessile organisms observed growing on an artificial substratum.

Our study provides the first experimental long-term assessment of the fouling communities growing in derelict fish traps in the Caribbean. Derelict fish traps may function as artificial reefs in terms of recruitment of both fish and marine sessile communities. The impetus for this study emerged from the need for a greater scientific understanding of derelict fish traps and how they function as part of coral reef ecosystems. Due to the lack of reliable information on the local trap fishery and derelict trap population in St. Thomas, U.S. Virgin Islands, assessment of fouling communities could provide a tool for predicting the time of immersion and the value of traps in supporting diverse and productive benthic communities including offering forage for grazing fish.

The primary objective of this study was to determine how derelict fish traps function as part of a coral reef ecosystem in terms of providing artificial substrate for

fouling organisms and also to determine if the development of fouling communities can be used to age derelict fish traps. The establishment of the benthic fouling communities on experimental derelict fish traps was documented for 12 months to assess changes in community composition, the influence of grazers on community structure and changes in trap condition.

Specific hypotheses were formulated and tested for all habitat strata:

H_1: Fouling organism can be used to determine how long derelict fish traps have been submerged

H_2: Fouling community composition is significantly different between habitat strata (inshore/offshore/close and far from reefs)

H_3: Fouling community composition is affected by grazers

H_4: Fouling communities follow a serial or sequential pattern of change

4.2 METHODS

Study Sites and Sampling Design

Twelve experimental derelict fish traps were deployed using a stratified sampling design that included near-reef and far-reef samples at both nearshore and offshore stations. The strata used for each station consisted of: 1.) sand immediately adjacent to a coral reef (within 1m); and 2.) sand or seagrass more distant from coral reefs (≥ 80 m). The inshore location, Perseverance Bay (18°20’22.96” N 64°59’34.73” W), is an open bay on the southern shore of St. Thomas, U.S. Virgin Islands, while the offshore location, Flat Cay (18°19’00.86” N 64°59’22.96” W) is a small uninhabited island approximately two kilometers south of St. Thomas (Figure

2). Both locations had been fished with traps historically as evidenced by sightings of derelict fish traps and actively fished traps.

Traps were surveyed using SCUBA once a month from January 2010 to January 2011 with twelve total surveys conducted for each trap. Field observations included visual surveys of fouling organisms and trap conditions. During each survey, the traps were sampled remotely using photography, whereby still images of all sides of each trap were recorded from a distance of approximately 1m using a 10 megapixel digital camera in an underwater housing. Traps were weighed with a crane scale prior to deployment and at the end of the twelve month study period to determine if a change in weight occurs due to encrustation and colonization of fouling organisms. Because any submerged material becomes covered in a biofilm within hours of submergence, the percent cover of a biofilm was only considered in the percent cover estimates if the substrate (trap materials) could not be seen underneath.

Photograph Analysis

Each trap was divided into three substrates for analysis purposes: the open, square areas between the mesh (henceforth referred to as inner mesh area), the wire mesh itself and the rebar frame. The inner mesh areas were systematically enumerated for each side of a trap and random numbers were also generated for each side. Based on the total number of mesh and inner mesh areas, 25% of that total count was calculated. The random numbers were used to determine exactly which inner mesh areas and mesh would be monitored for the duration of the study. This same process was also followed for the actual mesh, broken down into vertical and horizontal orientation for ease of assessment. The percent cover of fouling organism was

determined for each random point generated. Fouling organism were identified to the taxonomic level of Phylum (*Rhodophyta*, *Cholorphyta* etc.) as specimens were not collected to positively identify the species present with a microscope. Because any submerged material becomes covered in a biofilm within hours of submergence, the percent cover of a biofilm was only considered in the percent cover estimates if the substrate (trap materials) could not be seen underneath.

Data analysis

A suite of multivariate analyses in Primer v6 software (Clarke and Warwick 2001) were applied to examine differences and similarities in fouling communities by location and habitat. Non-metric multi-dimensional scaling (nMDS) was used to visually compare community similarities, analysis of similarities (ANOSIM) to test for significant differences and similarity percentages (SIMPER) to determine the contribution of species to assemblage dissimilarity. The index of multivariate seriation (IMS) (Clarke et al. 1993) was also applied to determine the degree to which fouling community change conformed to a linear or sequential sequence. Non-metric multi-dimensional scaling ordinations were again used however to better visualize the fouling community change in terms of the IMS, the ordinations were overlaid with a trajectory of each month sampled (Months 1-12).

4.3 RESULTS

During the twelve month study period, a biofilm and 12 phyla of fouling organisms were observed growing on the twelve experimental derelict fish traps. The phyla and or film with the highest average percent cover for the inner mesh (area

between wire mesh squares) were biofilm (0.49%), cyanobacteria (*Cyanophyta*, 0.30%), hydroids and anemones (*Cnidaria*, 0.21%), red algae (*Rhodophyta*, 0.03%) and tunicates (*Chordata*,subphylum *Urochordata*, 0.02%). The phyla and or film with the highest average percent cover for the actual mesh were biofilm (63.5%), crustose coralline algae (CCA), (Rhodophyta, 12.24%), Cyanophyta (1%), hydroids and anemones (0.80%) and hydrocoral (.53%). Again, the biolfim had the highest average percent cover on the rebar (65.7%) followed by CCA (6.9%), *Rhodophyta* (3.8%), *Mollusca* (2.0%) and *Cnidaria* (0.60%).

General trends in fouling community development

After one month all traps were covered with a biofilm. The biofilm and *Cnidaria* were the only groups present every month of the study on all three substrates. Initial colonization and disappearance patterns tended to vary with the different trap substrates (Table 4.3.1). The percent cover of fouling organisms gradually increased over time, but groups such as *Cyanophyta*, *Rhodophyta* tended to fluctuate over the course of the year with no discernable trend. Trends in the appearance of organisms were discernable among the three substrates; however the disappearance or indication of seasonal trends were not. Trends were more evident if only the top five groups were considered at the inshore and offshore locations for the inner mesh area (Figure 8) mesh (Figure 9) and rebar (Figure 10). Calcifying organisms such as Mollusca, *Milledporida* and *Scleractinia (Favia fragum)* were only recorded growing on the offshore traps. The percent cover of these organisms steadily increased over the twelve month period and did not fluctuate like the more ephemeral species. Although CCA was likely growing on all the traps, it could only be seen

growing on the inshore traps. Ascidians were first recorded after two months, only on the offshore traps.

Inshore versus offshore fouling community composition

The composition of fouling communities growing on the inner mesh area, mesh and rebar were all significantly different between inshore and offshore locations (Table 4.3.2). The nMDS ordination plots (not shown) provided good representations of the data and revealed clear separation in fouling community composition on the inner mesh area, mesh and rebar (stress= 0.13, 0.01 and 0.08 respectively).

The differences in the percent cover of the film and three phyla contributed approximately 90% to the community differences growing on the inner mesh at inshore and offshore locations. The biofilm and oysters (*Mollusca*) were more abundant on offshore traps contributing 56.4% and 4.8% to the difference respectively. *Cnidaria* and *Cyanophyta* were more abundant on inshore traps contributing 21.3% and 8.5% to the difference, respectively. Differences in the percent cover of the film and two phyla contributed approximately 95% of the difference between fouling communities growing on the wire mesh at inshore and offshore locations. The biofilm and cnidarians were more abundant on the offshore traps contributing 65.7% and 4.6% respectively, while CCA was more abundant on inshore traps contributing 20.85% to the difference. Finally, percent cover differences of the film and three phyla contributed approximately 77% to community differences growing in the rebar. The biofilm, *Rhodophyta* and *Mollusca* were more abundant offshore and contributed 27.3%, 13.7% and 9.2% respectively. The CCA was again more abundant inshore contributing 26.81% to the differences.

Near versus far from coral reef fouling community composition

The composition of fouling communities growing on the inner mesh area, mesh and rebar of the traps were not significantly different between near-reef and far-reef habitats as indicated by the low R-values and nMDS ordination plots (Table 4.3.2). The nMDS ordination plots did provide a good representation of the data (stress values=0.13, 0.10 and 0.05 for the inner mesh, mesh and rebar respectively), however a clear separation between habitats was not evident. Because of the high similarity, and lack of separation in fouling communities between the near-reef and far-reef habitats, a SIMPER analysis to determine what groups were driving the differences was not conducted.

Storm-induced trap movement

Movement was noted for seven and measured for four traps after the passage of Hurricane Earl through the territory on August 30-31, 2010. The eye of the storm passed within 69 miles of the study site and wind speeds in excess of 70 mph and a storm surge of 1-3 ft were recorded (NHC 2010; Gutro 2010). Three traps located in shallow inshore waters (20 ft depth) moved distances of approximately 20 m, 133 m and 155 m from their original locations. Three other inshore traps moved and have not been recorded. One offshore trap located in 40 ft of water moved approximately 3 m. Visual surveys of the seafloor conducted between the original locations and the post-hurricane locations for both the inshore and offshore traps revealed no obvious trap related damage to the substratum in September 2010 (1-2 weeks after the hurricane had passed).

Index of Multivariate Seriation

The index of multivariate seriation values indicated how closely fouling communities followed a sequential pattern of change. The IMS values for the innermesh and mesh substrates were relatively low (closer to 0), but were much higher for the rebar. Sequential patterns of change were the most evident in fouling communities growing on the rebar of traps (Appendix). With the exception of the three inshore, near-reef traps (hurricane data excluded), all traps had a significant p-value associated with its IMS value; therefore, there was not a complete absence of seriation (Table 4.3.3). A distinct change in the fouling community composition can be seen in the nMDS ordination for the inshore coral traps, the only three recovered from this site. The offshore trap that moved did not have a distinct change in community composition.

Grazing on fouling communities

At total of 384 fish comprising three families and six species, were observed grazing on the fouling communities growing on the experimental derelict fish traps. The species observed grazing included; *Scarus iserti* (Striped parrotfish, n=219), *S. taeniopterus* (Princess parrotfish, n=82), *Acanthurus bahianus* (Ocean surgeonfish, n=29), *Thalassoma bifasciatum* (Bluehead wrasse, n=22), *A. chirurgus* (Doctorfish, n=17) and *A. coeruleus* (Blue tang, n=15). Both parrotfish species were only present in their juvenile or initial life stages. Grazers were more abundant at the shallow inshore traps (n=281) and overall, 80% of the grazers were observed grazing on traps positioned in coral habitats. The average grazer size was 9cm ± 0.83 cm.

4.4 DISCUSSION

Fish traps lost or abandoned at sea eventually become colonized by sessile marine organisms. The characterization and development of fouling communities over time is just one aspect that helps scientists, manager and fishermen understand how derelict fish traps function as part of a coral reef ecosystem and potentially allow us to determine how long derelict traps have been submerged.

As expected, fouling communities were significantly different between locations. The phylum *Cnidaria* was more abundant growing on the shallower inshore traps than any other location. Hydroids were the major component of this phylum which have been documented in several studies as having decreased abundance with depth, thus accounting for their lower presence at the deeper offshore site (Hobbs and Azadan2010). Hobbs and Azadan (2010) also documented that substrate or bottom type did not present a clear pattern to discern differences in fouling community patterns as was also the case in this study with no significant differences in fouling community composition between near-reef and far-reef habitats.

Trends in fouling community development were present; however patterns in first appearance were more discernable than when groups disappeared or when their presence was no longer observed. The lack of discernable patterns makes it difficult to identify seasonal trends and therefore more long-term data may need to be collected to separate seasonal changes from predation or stochastic events. The index of multivariate seriation values indicated that the fouling communities growing on the inner mesh, mesh and rebar substrates on most traps did have a discernable pattern of

biotic change over the twelve month study period; however with the exception of the rebar, the IMS values for the inner mesh and mesh were relatively low suggesting that a sequential change in community composition is occurring but not in a very gradual manner. The fouling communities growing on the rebar of each trap were much closer to 1, indicating that the communities were changing in a smooth, regular fashion. The rebar is much more stable substrate than the inner mesh or mesh areas, which in turn allowed for a more stable fouling community.

The three inshore near-reef traps that were moved by Hurricane Earl and then recovered did not have a discernable biotic pattern if the pre-Hurricane data is excluded. This may be due to the environmental conditions at the near-reef site as Perseverance Bay is shallow and often subjected to swells, in addition to other disturbances such as predation that could also alter the fouling communities. The traps were moved by the hurricane presumably in a rolling motion, as two of the recovered traps were found upside down. This disturbance opened up space for new fouling organisms, as the fouling communities observed growing prior to the hurricane were much different, which is also indicated by the nMDS ordinations for these traps (Cifuentes et al. 2007). Although the process of fouling community development is complex, in most studies, the initial steps of establishment and development follow the same basic pattern regardless of location and substrate type, known as the sequence fouling model developed by Wahl (1989). Once initial settlement has occurred, it is difficult to determine a further sequence of fouling community development due to the trouble in distinguishing between true succession and seasonal progression of the communities (Scheer 1945).

Colonization by fouling organisms is structured by physical factors such as currents, water depth, distance from shore and water quality (Svane 2001) and also by biological factors such as larval availability, recruitment, predation and survival. Time of immersion, for instance during different seasons, can cause variations in fouling community colonization due to the seasonality associated with larval availability and recruitment (Saldhana et al. 2003; Fitzhardinge 1989). Excluding Hurricane Earl, the only other type of disturbance to fouling communities directly observed was predation by herbivorous grazers. Herbivores were frequently observed grazing on the experimental traps especially at the inshore, near-reef site. Grazing by herbivores may have influenced the structure of the fouling communities as the percent cover of the biofilm was lower at the inshore, near-reef site which allowed CCA to dominate. Crustose coralline algae growth is better in shallow areas, which is another factor in addition to grazing that allowed for a higher percent cover inshore (Borowitzka et al. 1978). Grazing however has also caused community shifts from one dominated by multiple species of algae to one dominated by filamentous, cyanopytes, which also occurred at the inshore, near-reef site (Sammarco 1983).

Based on the development of fouling communities in this one year study, more long-term monitoring (> 1 year) may be needed to determine which species are truly affected by seasons. Species that appear to be less affected by seasons and predation may be better indicators of the age of derelict fish traps. The percent cover of distinct species such as fire coral, stony coral and oysters may provide some information as to how long traps have been submerged as they are more affected by larval recruitment and space availability than by grazing or dislodgement like ephemeral species.

Saldahana et al. (2003) documented that oysters can be used to age derelict fish nets, however for an accurate estimate they must be removed and the cross sectional rings examined. The higher IMS values for the rebar, suggest that it is a more stable substrate and that following the fouling communities growing on those parts of the traps may provide a better estimate of the age than those on the less stable substrates such as the mesh and inner mesh.

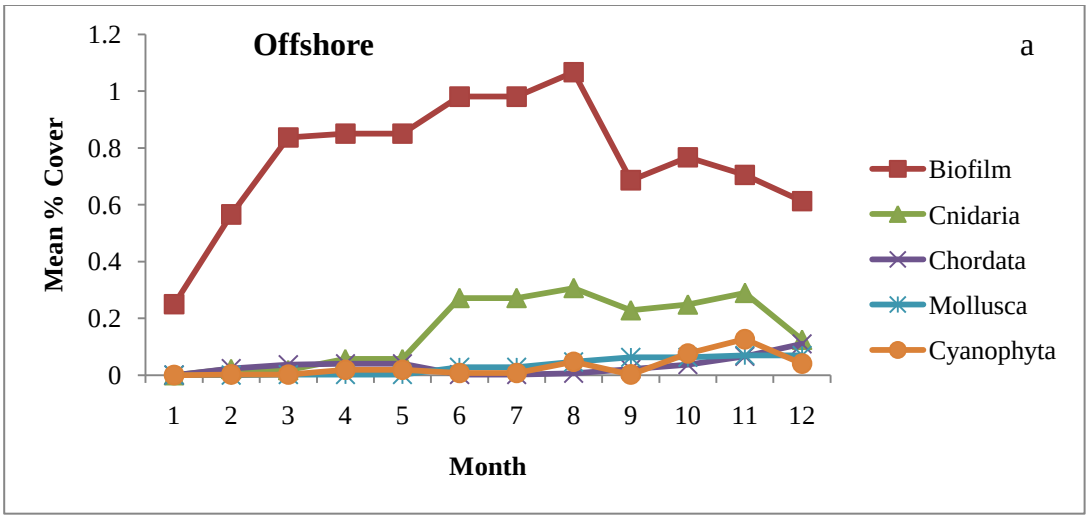
Derelict fish traps provide a new, open substrate for members of the benthic community to settle on. Studying patterns of colonization provides an indication of not only what species are capable of fouling derelict fish traps but also how coral reef communities develop over time. Derelict fish traps essentially function as artificial reefs to members of both the fish and benthic communities. In areas where reef restoration is needed, studying the general patterns of colonization on three dimensional structure can provide insight as to how new space is colonized and utilized by members of coral reef communities and even what materials may be the most suitable for colonization. Following the fouling community composition of ephemeral species may not be a good indication of age as they are easily disturbed by grazers and water currents. Calcifying species such as mollusks, fire and scleractinian corals may be better indicators of derelict trap age as well as species growing on the rebar frame as they are less easily disturbed. Caution should be exerted using these species however as settlement highly depends on what is present in the water column at the time of immersion.

Table 4.3.1. Presence or absence of groups observed growing on the experimental derelict traps from January 23, 2010-January 23, 2011. Symbols represent the three trap substrates; Innermesh (**X**), Mesh (●), Rebar (■).

	Month											
Group	1	2	3	4	5	6	7	8	9	10	11	12
Biofilm	X●■	X●■	X●■	X●■	X●■	X●■	X●■	X●■	X●■	X●■	X●■	X●■
Rhodophyta	-	■	X●■	X●■	X●■	X●■	X●■	X●■	X●■	●■	●■	●■
Cholorphyta	-	-	X■	X■	X■	X■	X■	X■	X■	X■	X■	X■
Phaeophyta	-	-	-	X●	X●	X●	X●■	X●■	X●■	X●■	●■	●■
Chordata	-	X■	X●■	X●■	X●■	X●■	X■	X■	X■	X●■	X●■	X●■
CCA	●■	●■	●■	●■	●■	●■	●■	●■	●	-	-	-
Mollusca	-	■	X■	X■	X■	X■	X●■	X●■	X●■	X●■	X●■	X●■
Porifera	-	-	■	■	■	X■	X●	X	●	●	●	●■
Millsporida	-	-	-	-	-	-	●	●	●■	X●■	X●■	X●■
Scleractinia	-	-	-	-	-	-	-	■	●■	●■	●■	X●■
Tube Worms	-	-	■	X■	X■	■	■	●■	X■	X■	X■	X■
Cyanophyta	-	X	X●■	X●■	X●■	X●■	X●■	X●■	X●■	X●■	X●■	X●■

Table 4.3.2. ANOSIM analysis results comparing the percent cover of fouling community assemblages between locations and habitats. Asterisks indicate significant differences.

	Inshore vs. Offshore		**Near-reef vs. Far-reef**	
Substrate	**Global R**	**p-value**	**Global R**	**p-value**
Inner mesh	0.684	0.001*	0.035	0.001
Mesh	0.41	0.001*	0.033	0.001
Rebar	0.42	0.001*	0.095	0.001



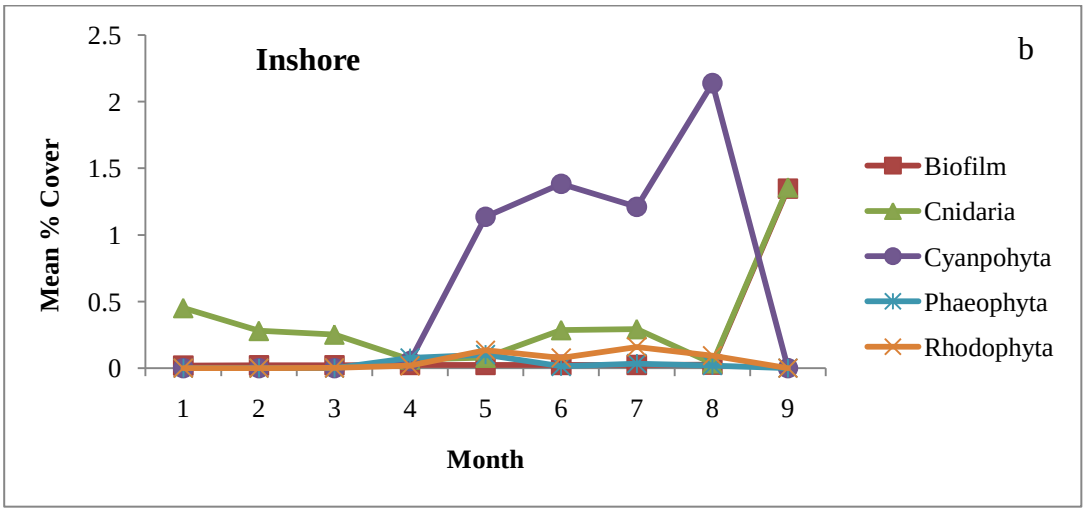
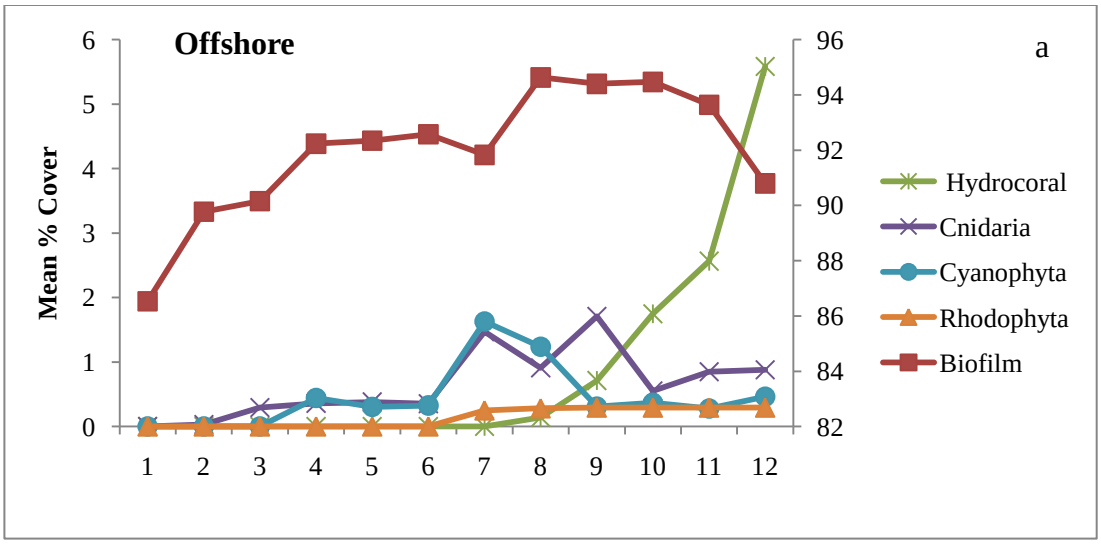


Figure 4.3.1. Groups with the highest percent cover growing over the inner mesh area at the offshore (a) and inshore (b) locations.



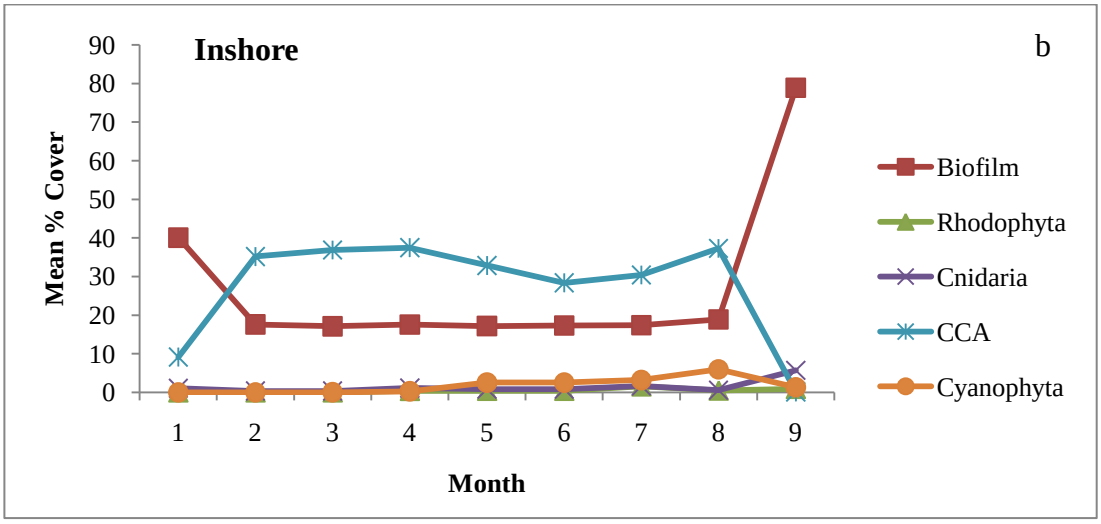
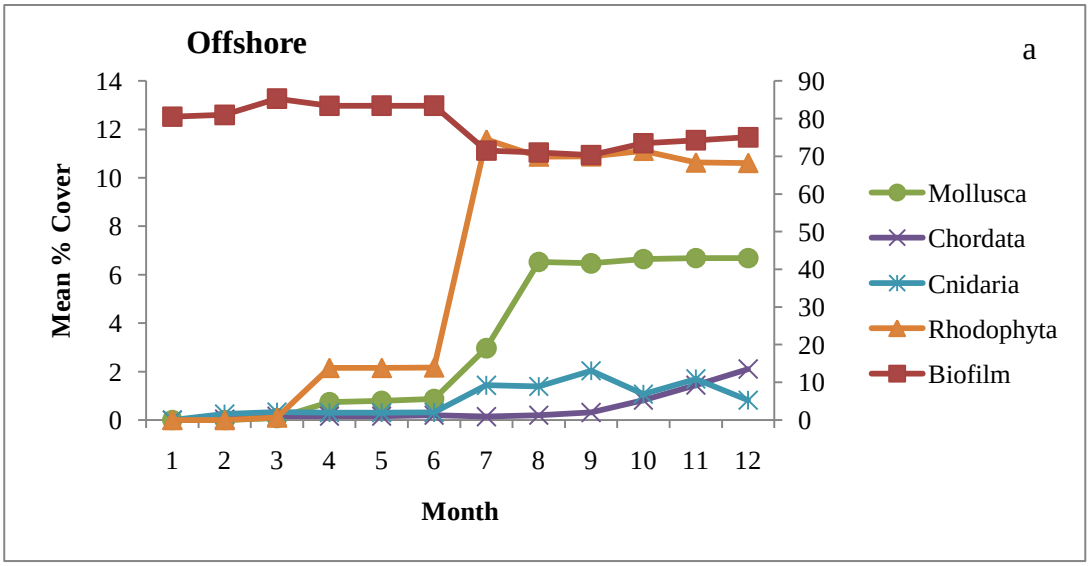


Figure 4.3.2. Groups with the highest percent cover growing on the mesh at the offshore (a) and inshore (b) locations. The biolfim (a) is measured on the secondary Y_2 axis. All other variables are measured on the primary Y_1 axis.



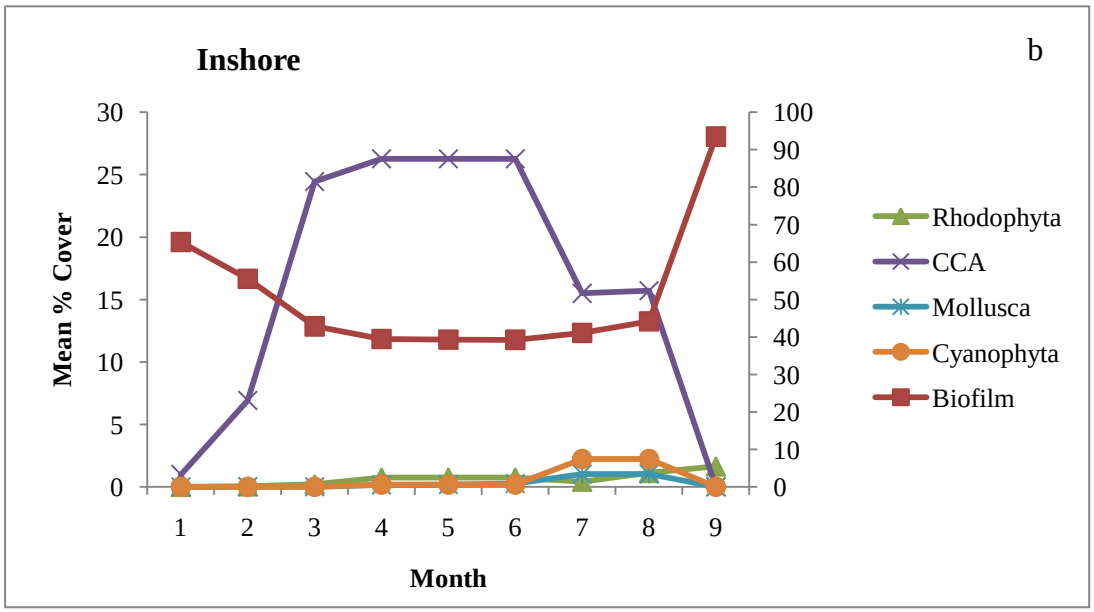


Figure 4.3.3. Groups with the highest percent cover growing on the rebar at the offshore (a) and inshore (b) locations. The biofilm (a and b) is measured on the secondary, Y_2 axis. All other variables are measured on the primary Y_1axis.

Trap	Location	Habitat	Inner Mesh		Mesh		Rebar	
			IMS	p-value	IMS	p-value	IMS	p-value
1	Offshore	Near-reef	0.41	0.001	0.451	0.001	0.901	0.001
2	Offshore	Near-reef	0.52	0.001	0.474	0.001	0.88	0.001
3	Offshore	Near-reef	0.566	0.001	0.29	0.001	0.889	0.001
4	Offshore	Far-reef	0.279	0.001	0.284	0.001	0.787	0.001
5	Offshore	Far-reef	0.232	0.001	0.412	0.001	0.822	0.001
6	Offshore	Far-reef	0.33	0.001	0.42	0.001	0.71	0.001
7	Inshore	Near-reef	0.535 (0.676)	0.001 (0.001)	0.537 (0.543)	0.001 (0.001)	0.340 (0.568)	.0044 (0.007)
8	Inshore	Near-reef	0.435 (0.296)	0.001 (0.001)	0.438 (0.352)	0.001 (0.001)	0.449 (0.447)	0.007 (0.025)
9	Inshore	Near-reef	0.246 (0.053)	0.001 (0.086)	0.445 (0.378)	0.001 (0.001)	0.581 (0.763)	0.001 (0.001)
10	Inshore	Far-reef	0.223	0.001	0.568	0.001	0.553	0.005
11	Inshore	Far-reef	0.226	0.002	0.537	0.001	0.585	0.002
12	Inshore	Far-reef	0.185	0.002	0.352	0.001	0.795	0.001

CHAPTER 5: GENERAL CONCLUSION

A successful sustainable fishery is dependent upon not only the function of active fishing gear, but also derelict gear. Understanding the basic knowledge of the gear selectivity and performance, the behavior of the fish being caught as well as the ecological processes that can affect the condition of the gear are important for thoroughly evaluating the impacts of derelict fishing gear and proper management thereafter. The results of this study have increased the knowledge of the function of derelict fish traps by examining them as an integral part of a coral reef ecosystem and completing quantitative assessments of ghostfishing, fish behavior and colonization of fouling communities. The impact of ghostfishing will be a function of the trap condition and the behavioral responses of fish which may change over time depending on the materials used and the colonization of fouling organisms.

In order to reduce the impacts of derelict fish traps and the population of submerged marine debris, simple modifications to fishing practices and gear design modifications should be considered. For example, traps could alternatively be disposed of on land rather than at sea, and escape gaps cold be incorporated into already existing traps to aid in the reduction of bycatch. The feasibility of escape gaps is currently being evaluated by the National Marine Fisheries Service and St. Thomas Fishermen's Association. The escape gap efforts are being supported by the results of TrapCam video footage by providing information on what sizes and placements of escape gaps should be used for experimental trials. All suggestions of modifications to fishing practices and gears should be examined and evaluated by the fishing community and supported by marine management agencies. Future work should further evaluate the impacts of ghostfishing by determining compliance of fishermen

with federal and territorial gear regulations, such as the use of a proper biodegradable rot cord for escape panels. Tests should examine different materials used to close escape panels and determine how long they enable derelict traps to ghostfish under different trap use scenarios such as traps that have been hauled at regular intervals as well as traps that are new and have been lost at sea. Future work should also focus on determining a more advanced, reliable method for estimating the age of derelict fish traps.

CHAPTER 6: BIBLIOGRAPHY

Agar, J.J., Shivlani, M., Waters, J.R.,Valdes-Pizzini, M., Murray, T., Kirkley. J., Suman, D., 2005. U.S. Caribbean fish trap fishery costs and earnings study. NOAA Tech. Mem. NMFS-SEFSC-534, 127 p.

Al-Masroori, H., Al-Oufi, H., McIlwain, J.L., McLean, E., 2004. Catches of lost fish traps (ghost fishing) from fishing grounds near Muscat, Sultanate of Oman. Fish. Res. 69 (3), 407-414.

Bailey-Brock, J.H., 1989. Fouling community development on an artificial reef in Hawaiian waters. Bull. Mar. Sci. 44(2), 580-591.

Bardach, J.E., Magnuson, J.J., 1980. Introduction and perspectives. In: Bardach, J.E., Magnuson, J.J., May, R.C. & Reinhar, J.M. (eds.) Fish behavior and its use in the capture and culture of fishes. ICLARM 5, 1-31.

Barnes, H., 1963. Underwater television. Oceanogr. Mar. Biol. Annu. Rev. 1, 115–28.

Barry, T.P., Lapp, A.F., Kayes, T.B., Malison, J.A., 1993. Validation of a microtitre plate ELISA for measuring cortisol in fish and comparison responses of rainbow trout (*Oncorhynchus mykiss*) and lake trout (*Salvelinus namaycush*). Aquaculture 117, 351-363.

Bauer, L.J., Kendall, M.S., Jeffrey, C.F.G., 2008. Incidence of marine debris and its relationships with benthic features in Gray's Reef National Marine Sanctuary, Southeast USA. Mar. Poll. Bull. 56(3), 402-413.

Blaxter, J.H.S., 1980. Vision and the feeding of fishes. In: Bardach, J.E., Magnuson, J.J., May, R.C. & Reinhar, J.M. (eds.) Fish behavior and its use in the capture and culture of fishes. ICLARM 5, 32-56.

Bohnsack, J., 1989. Are high densities of fishes at artificial reef the result of habitat limitation or behavioral preference. Bull. Mar. Sci. 44(2), 631-645.

Borowitzka, M.A.m Larkum, A.W.D., Borowitzkam L.J., 1978. A preliminary study of algae turf communities of a shallow coral reef lagoon using an artificial substratum. Aquat.Bot. 5, 365-381.

Brokovich, E., Baranes, A., Goren, M., 2006. Habitat structure determines coral reef fish assemblages at the northern tip of the Red Sea. Ecol. Indic. 6(3), 494-507.

Brown, C., Gardner, C., Braithwaite, V.A., 2005. Differential stress response in fish from areas of high- and low-predation pressure. J. Comp. Physiol., B 175, 305-312.

Bullimore, B.A, Newman, P.B., Kaiser, M.J., Gilbert, S.E., Lock, K.M., 2001. A study of catches in a fleet of ghost fishing pots. Fish. Bull. 99, 247-253.

Cappo, M., Harvey, E., Shortis, M., 2006. Counting and measuring fish with baited video techniques-an overview. In: Lyle, J.M., Furlani, D.M. & Buxton, C.D. (Eds.), Cutting- edge technologies in fish and fisheries science, AFSB Conference and Workshop Australian Society for Fish Biology, Hobart, Tasmania, 101-114.

Cifuentes, M., Kamlah, C., Thiel, M., Lenz, M., Wahl, M., 2007. Effects of temporal variability of disturbance on the succession in marine fouling communities in northern-central Chile. J. Exp. Mar. Biol. Ecol. 352(2), 280-294.

Chopin, F.S. & Arimotoa, T., 1995. The condition of fish escaping from fishing gears-a review. Fish. Res. 21, 315-327.

Chopin, F.S., Arimoto, T., Inoue, Y., 1996. A comparison of the stress response and mortality of sea bream *Pargus major* captured by hook and line and trammel net. Fish. Res. 28, 277-289.

Clarke, K.R., Warwick. R.M., Brown, E.E., 1993. An index shoring breakdown of seriation, related to disturbance, in a coral-reef assemblage. Mar. Ecol. Prog. Ser. 102, 153-160.

Clarke, K.R., Warwick R.M., 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E, Plymouth.

Connell, S.D., 2001. Urban structure as marine habitats: an experimental comparison of the composition and abundance of subtidal epibiota among pilings, pontoons and rocky reefs. Mar. Envir. Res. 52(2), 115-125.

Corbin, C.J., Singh, J.G., 1993. Marine debris contamination of beaches in St. Lucia and Dominica. Mar. Poll. Bull. 26(6), 325-328.

Cummings, S.L., 1994. Colonization of a nearshore artificial reef at Boca Raton (Palm Beach County, Florida). Bull. Mar. Sci. 55(2-3), 1193-1215.

David, B.O., Closs, P., 2001. Continuous remote monitoring of fish activity with restricted home ranges using radiotelemetry. J. Fish Biol. 59, 705- 715.

Froese, R., Pauly, D., 2010. Fishbase. Accessed 13 Oct. 2010. www.fishbase.org.

Garcia, C.B., Salzwedel, H., 1995. Successional patterns on fouling plates in the Bay of Santa Marta, Colombian Caribbean..Anales del Instituto de Investigaciones Marinos Punta Betin 24, 95– 121.

Gobert, B., 1998. Density-dependent size selectivity in Antillean fish traps. Fish. Res. 38 (2), 159-167.

Gutro, R., 2010. Hurricane season 2010: Hurricane Earl (North Atlantic Ocean). NASA Goddard Space Flight Center, Breenbeldt, MD. Accessed 11 Nov. 2010.http://www.nasa.gov/mission_pages/hurricanes/archives/2010/h2010_Earl.html

Hawkins, J.P., Roberts, C.M., Gell, F.R., Dytham, C., 2007. Effects of trap fishing on reef fish communities. Aquatic Conserv: Mar. Freshw. Ecosyst. 17, 111-132.

Helfman, G.S., 1993. Fish behavior by day, night and twilight. In: Pitcher, T.J. (Ed.), Behavior of teleost fishes 2nd Edition, 479-507.

Hess, N.A., Ribic, C.A., Vining, I., 1999. Benthic marine debris, with an emphasis on fishery-related items, surrounding Kodiak Island, Alaska, 1994–1996. Mar. Poll. Bull. 38, 885–890.

High, W.L., Beardsley, A.J., 1970. Fish behavior studies from an undersea habitat. Comm.Fish. Rev. 32(10), 31-37.

Hobbs, N., Azadan. C., 2010. Marine invasive species benthic fouling study. Salem Sound Coastwatch Report. 25pp.

Holmes, N.J., Harriott, V.J., Banks, S.A. ,1997. Latitudinal variation in patterns of colonization of cryptic calcareous marine organisms. Mar. Ecol. Prog. Ser. 155, 103-113.

Hopkins, T.E., Cech, Jr, J., 1992. Physiological effects of capturing striped bass in gillnets and fyke traps. Trans. Amer. Fish. Soc. 12 1**,** 819-822.

Hughes, T.P., 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 9, 1547-1551.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J. & Warner, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 27, 629-637.

Johnson, A.E., 2010. Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability. Mar. Ecol. Prog. Ser. 415, 201-209.

Jury, S.H., Howell. H., Grady, D.F., Watson, W.H. III., 2001. Lobster trap video: in situ video surveillance of the behavior of *Homarus americanus* in and around traps. Mar.Fresh. Res. 52, 1125-1132.

Keenleyside, H.H.A., 1955. Some aspects of the schooling behaviour of fish. Behaviour 8, 183–248.

Kendall, M.S., Kruer, C.R., Buja, K.R., Christensen, J.D., Finkbeiner, M., Monacao, M.E., 2001. Methods used to map the benthic habitats of Puerto Rico and the U.S. Virgin Islands. NOAA/NOS Biogeography Tech. Report. Silver Spring, MD, pp. 45.

Laist, D.W., 1995. Marine debris entanglement and ghost fishing: a criptic and significant type of bycatch. In: Proceedings of the Solving Bycatch Workshop, September 25-27, 1995, Seattle, Washington, 33-40.

Lewis, C. F.,. Slade, S.L., Maxwell, K.E.,. Matthews, T.R., 2009. Lobster trap impact on coral reefs: effects of wind-driven trap movement. N.Z. J. Mar. Freshwat. Res. 43, 271–282

Luckhurst, B., Ward, J.W., 1987. Behavioral dynamics of coral reef fishes in Antillian fish traps at Bermuda. Proc. Gulf. Carib. Fish. Inst. 38, 528-546.

Macfadyen, G., Huntington, T., Cappell.R., 2009. Abandoned, lost or otherwise discarded fishing gear. UNEP Regional Seas Reports and Studies, No. 185; FAO Fisheries and Aquaculture Technical Paper, No. 523. Rome, UNEP/FAO. 2009. pp. 115.

Magurran, A.E., Irving, P.W., Henderson, P.A., 1996. Is there a fish alarm pheremone? A wild study and critique. Proc. Biol. Sci. 263(1376), 1551-1556.

Matsuoka, T., Nakashima, T., Nagasawa, N., 2005. A review of ghost fishing: scientific approaches to evaluation and solutions. Fish. Sci. 71(4), 691-702.

Marshak, A.R., Hill, R.L., Sheridan, P., Scharer, M., Apeldoorn, R.S., 2007. In-situ observations of Antillean fish trap contents in Southwest Puerto Rico: relating catch to habitat and damage potential. Proc. Gulf Car. Fish. Inst. 60, 447-453.

Matthews, K. R., 1985. Species similarity and movement of fishes on natural and artificial reefs in Monterey Bay, California. Bull. Mar. Sci. 37, 252–270.

Munro, J.L., Sary, Z, Gel, F.R., 1971. Dynamic factors affecting the performance of the Antillean fish trap. Proc. Gulf Carib. Fish. Inst. 23, 184-194.

Munro. J.L., 1974. The mode of operation of Antillean fish traps and the relationships between ingress, escapement, catch and soak. J. Cons. Int. Explor. Mer. 35(3), 337-350.

National Hurricane Center, 2010. Hurricane Earl. Accessed 11 Nov. 2010. http://www.nhc.noaa.gov/archive/2010/al07/al072010.fstadv.019.shtml?

Olsen, D.A., 2008. Bycatch studies of reef fish in support of Caribbean Fishery Management Council preferred options for fishery management in St. Thomas, U.S. Virgin Islands. MARFIN- NA06NMF4330052. pp. 26.

Pawson, M.G., 2003. The catching capacity of lost static fishing gears: introduction. Fish. Res. 64 (2-3), 101-105.

Popper, A.N., Lu, Z., 2000. Structure-function relationships in fish otolith organs. Fish. Res. 46(1-3), 15-25.

Pratt, T.C., Smokorowski, K.E., Muirhead, J.R., 2005. Development and experimental assessment of an underwater video technique for assessing fish-habitat relationships. Archiv fuer Hydrobiologie 164 (4), 547- 571.

Recksiek, C.W., Appeldoorn, R.S., Turingan, R.G., 1991. Studies of fish traps as stock assessment devices on a shallow reef in south-western Puerto Rico. Fish. Res. 10, 177-197. Robichaud, D., Hunte, W., Chapman, M.W., 2000. Factors affecting the catchability of reef fishes in Antillean fish traps. Bull. Mar. Sci. 67(2), 831-844.

Robichaud, D., Hunte, W., Chapman, M.W., 2000. Factors affecting the catchability of reef fishes in Antillean fish traps. Bull. Mar.Sci. 67(2), 831-844.

Saldanha, H.J., Sancho, G., Santos, M.N., Puente, E., Gaspar, M.B., Bilbao, A., Monteiro, C.C., Gomez, E., Arregi, L., 2003. The use of biofouling for ageing lost nets: a case study. Fish. Res. 64, 141-150.

Sammarco, P.W., 1983. Effects of fish grazing and damselfish territoriality on coral reef algae.I. Algal community structure. Mar. Ecol. Prog. Ser. 13:1-14.

Scheer, B.T, 1945. The development of marine fouling communities. Biol. Bull. 89(1), 103-121.

Sheridan, P.F., Hill, R.L., Kojis, B.L., 2006. Trap fishing in the U.S. Virgin Islands: How and where effort is exerted. Proc. Gulf. Carib. Fish. Inst. 57, 175-188.

Skomal, G.B., 2007. Evaluating the physiological and physical consequences of capture on post-release survivorship in large pelagic fishes. Fish. Manag.Ecol. 14, 81-89.

Smith, T.B., Nemeth, R.S., Blondeau, J., Calnan, J.M., Kadison, E., Herzlieb, S., 2008. Assessing coral reef health across onshore to offshore stress gradients in the U.S. Virgin Islands. Mar. Poll. Bull. 56(12), 1983-1991.

Smolowitz, R.J., 1978. Trap design and ghost fishing: An overview. Mar. Fish. Rev. 40, 2-8.

Stefatos, A., Charalampakis, M., Paptheodrou, G., Ferentinos, G., 1999. Marine debris on the seafloor of the Mediterranean Sea: Examples from two enclosed gulfs in Western Greece. Mar. Poll. Bull. 38(5), 389-393.

Stoner, A.W., 2004. Effects of environmental variables on fish feeding ecology implications for the performance of baited fishing gear and stock assessment. J. Fish Biol. 65, 1445-1471.

Sutherland, J.P., Karlson, R.H., 1977. Development and stability of the fouling community at Beaufort, North Carolina. Ecol. Monogr. 47, 425-446.

Svane, I., Petersen, J.K., 2001. On the problems of epibioses, fouling and artificial reefs, a review. Mar. Ecol. 22(3), 169-188.

U.S.V.I. D.P.N.R., 2009. United States Virgin Islands commercial and recreational fisher's information booklet. Department of Planning and Natural Resources,

Division of Fish and Wildlife and Division of Environmental Enforcement, pp. 42.www.vifishandwildlife.com/fish.html.

Wahl, M., 1989. Marine epibiosis. I. Fouling and antifouling: some basic aspects. Mar. Ecol. Prog. Ser. 58, 175-189.

Warwick, R.M., Ashman, C.M., Brown, A.R., Clarke, K.R., Dowell, B., Hart, B., Lewis, R.E., Shillabeer, N., Somerfield, P.J., Tapp, J.F. 2002. Inter-annual changes in biodiversity and community structure of the macrobenthos in Tees Bay and the Tees estuary, UK, associated with local and regional environmental events. Mar. Ecol. Prog. Ser. 234, 1-13.

Ward, A.J., Duff, A.J., Horsfall, J.S., Currie, S., 2008. Scents and scents-ability: pollution disrupts chemical social recognition and shoaling in fish. Proc. R. Soc. Lond. Biol. 1630, 101-105.

Weber, J., Haman, F., 1996. Pathways for metabolic fuels and oxygen in high performance fish. Comp. Biochem. Physiol. 113A (1), 33-38.

Wolff, N., Grober-Dunsmore, R., Rogers, C.S., Beets, J., 1999. Management implications of fish trap effectiveness in adjacent coral reef and gorgonian habitats. Environ. Biol. Fishes 55, 81-90.

APPENDIX

NON-METRIC MULTI-DIMENSIONAL SCALING ORDINATIONS OF FOULING COMMUNITY SERIATION

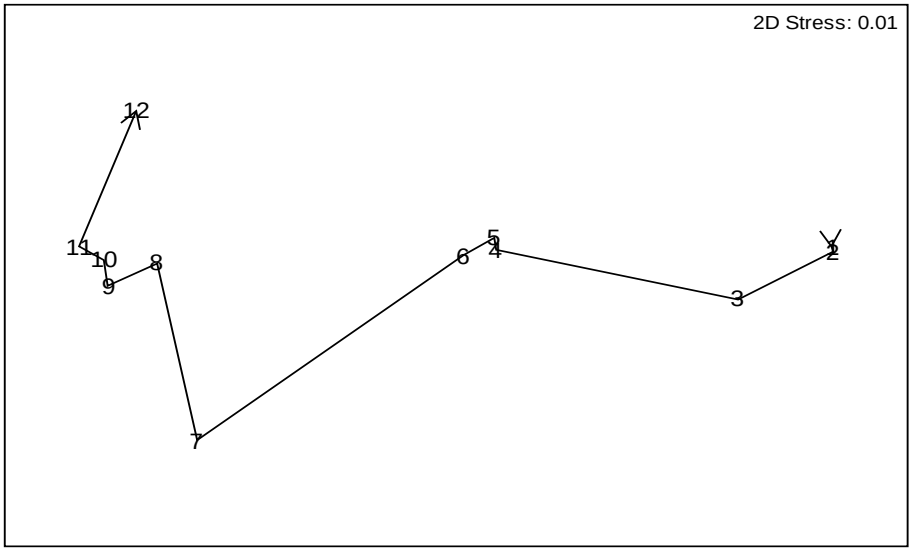


Figure 1. Seriation of fouling communities growing on the rebar of trap 1, located at the offshore, near-reef site. The numbers indicate months 1-12.

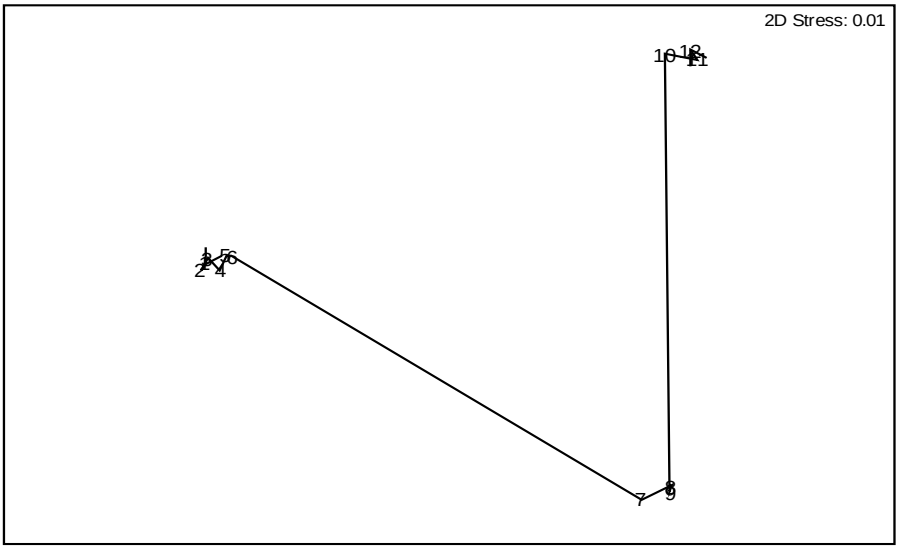


Figure 2. Seriation of fouling communities growing on the rebar of trap 2, located at the offshore, near-reef site. The numbers indicate months 1-12.

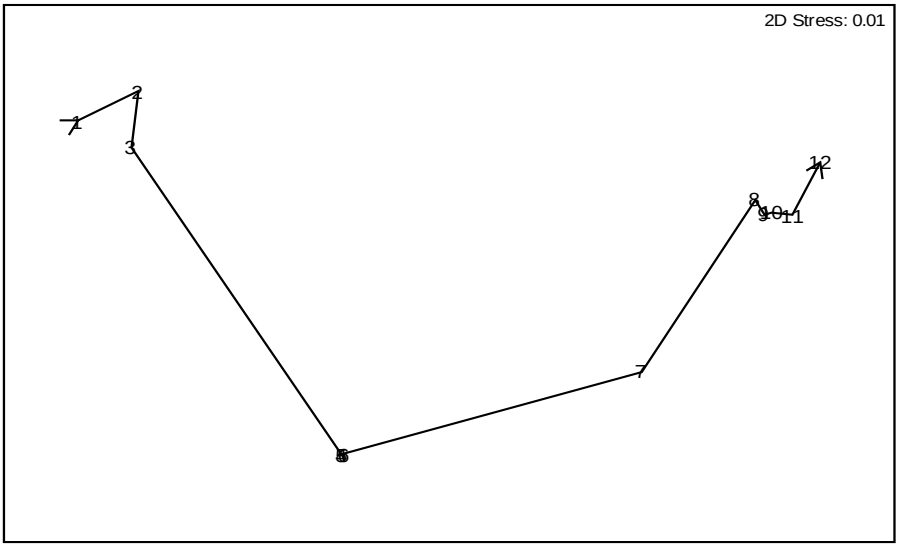


Figure 3. Seriation of fouling communities growing on the rebar of trap 3, located at the offshore, near-reef site. The numbers indicate months 1-12.

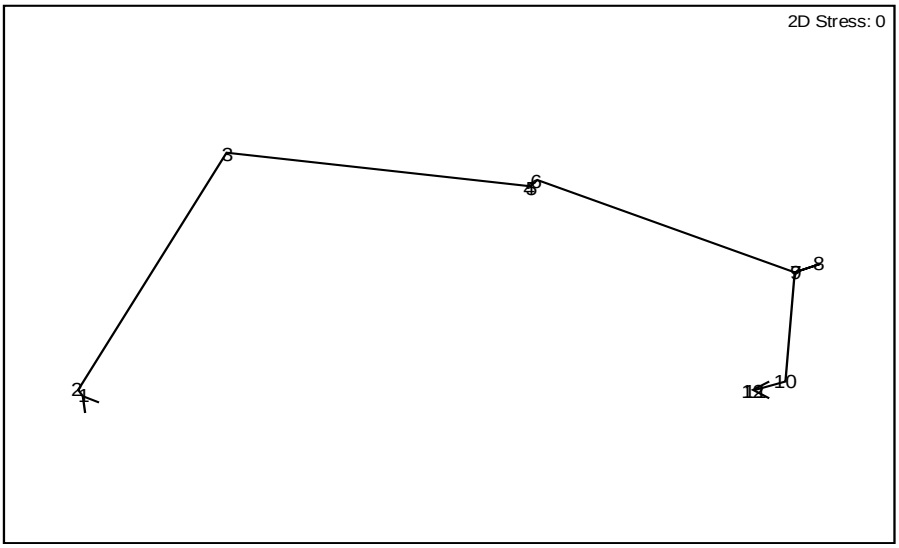


Figure 4. Seriation of fouling communities growing on the rebar of trap 4, located at the offshore, far-reef site. The numbers indicate months 1-12.

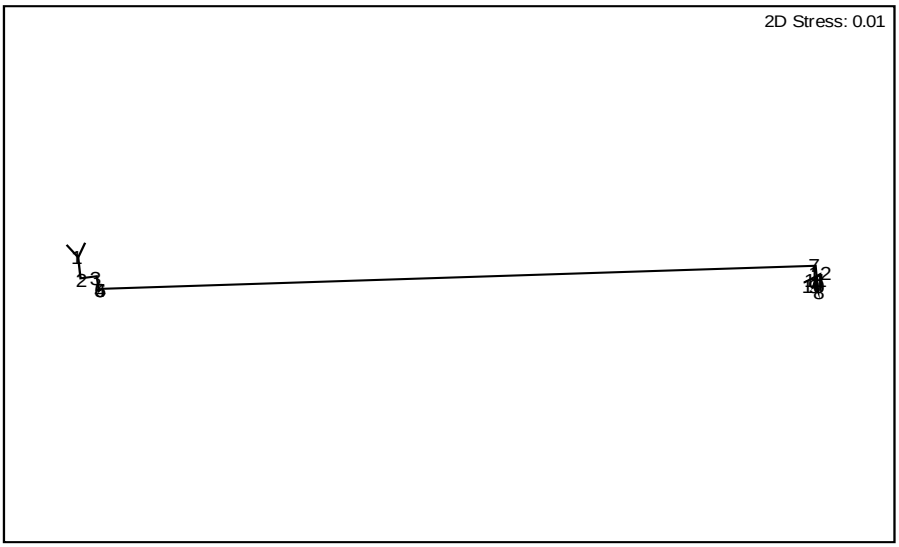


Figure 5. Seriation of fouling communities growing on the rebar of trap 5, located at the offshore, far-reef site. The numbers indicate months 1-12.

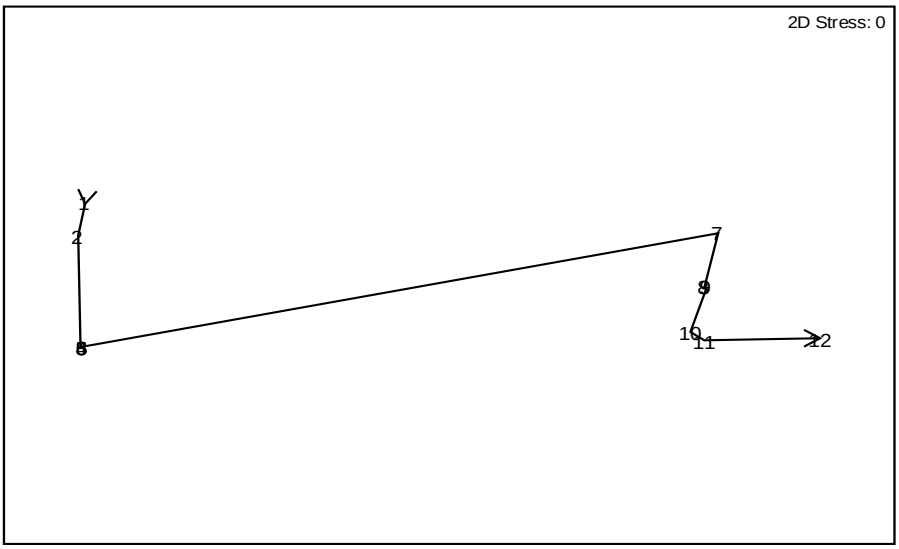


Figure 6. Seriation of fouling communities growing on the rebar of trap 6, located at the offshore, far-reef site. The numbers indicate months 1-12.

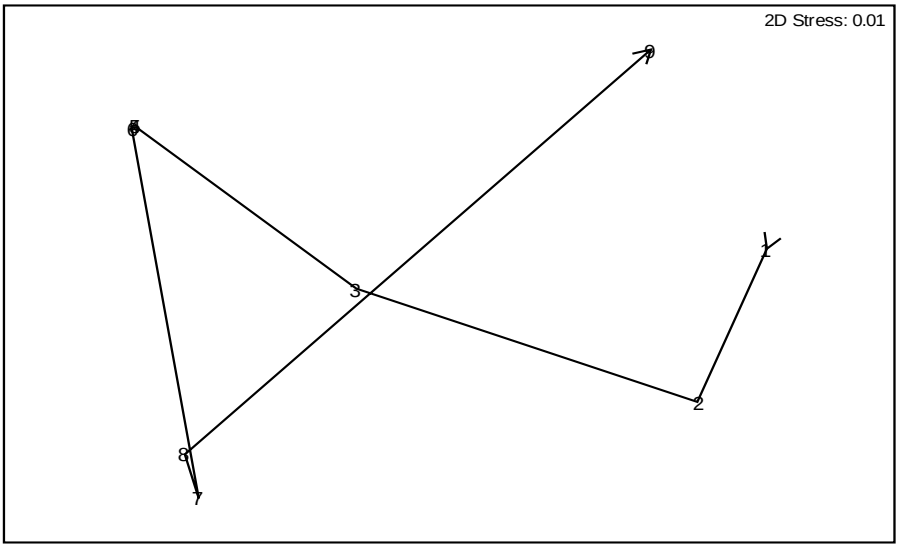


Figure 7. Seriation of fouling communities growing on the rebar of trap 7, located at the inshore, near-reef site. The numbers indicate months 1-9. This trap was lost and recovered after Hurricane Earl.

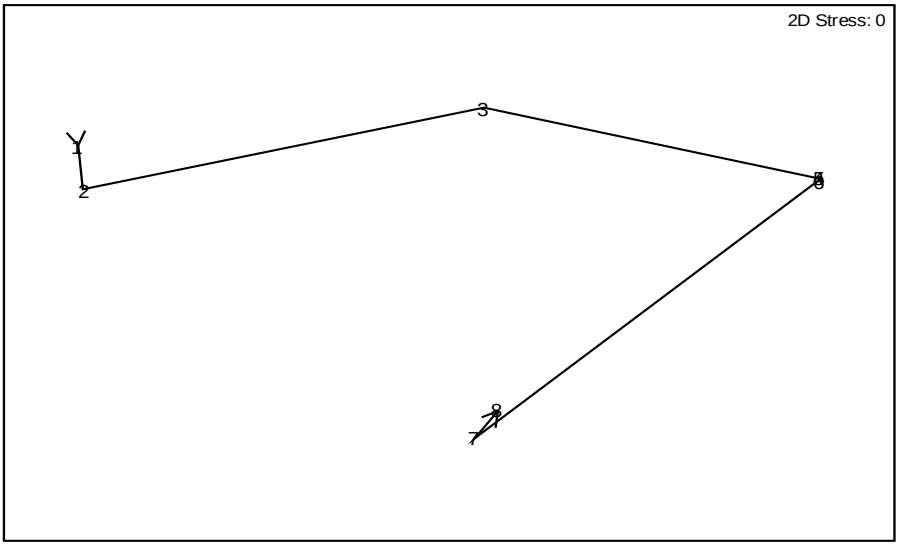


Figure 8. Seriation of fouling communities excluding the effects of Hurricane Earl, growing on the rebar of trap 7, located at the inshore, near-reef site. The numbers indicate months 1-8.

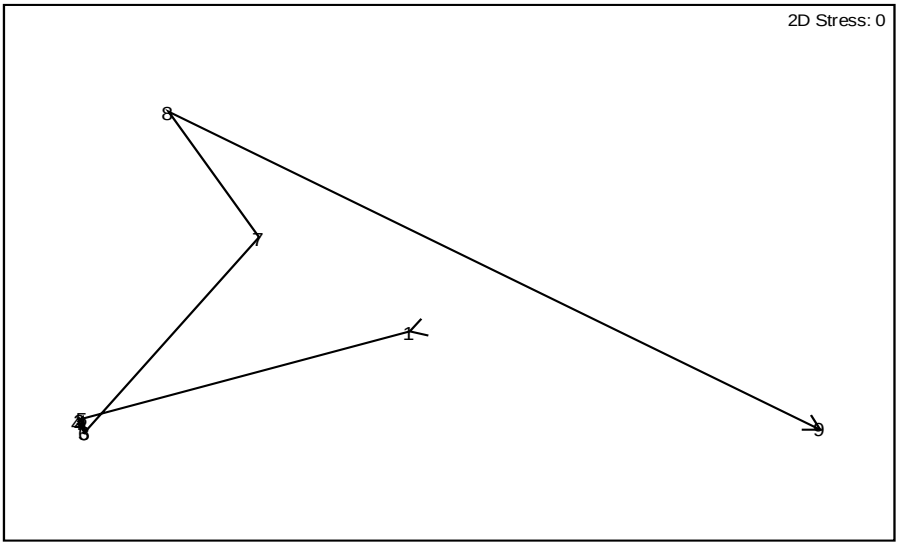


Figure 9. Seriation of fouling communities growing on the rebar of trap 8, located at the inshore, near-reef site. The numbers indicate months 1-9. This trap was lost and recovered after Hurricane Earl.

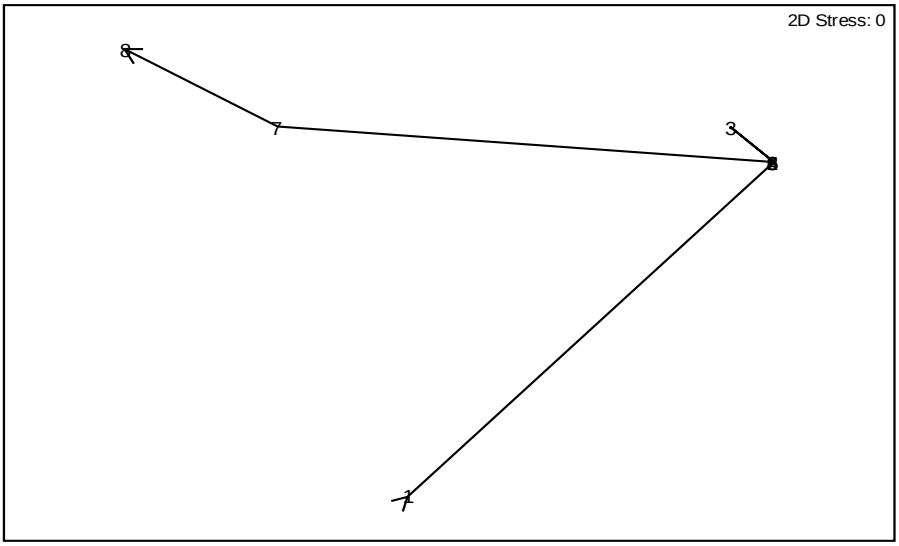


Figure 10. Seriation of fouling communities excluding the effects of Hurricane Earl, growing on the rebar of trap 8, located at the inshore, near-reef site. The numbers indicate months 1-8.

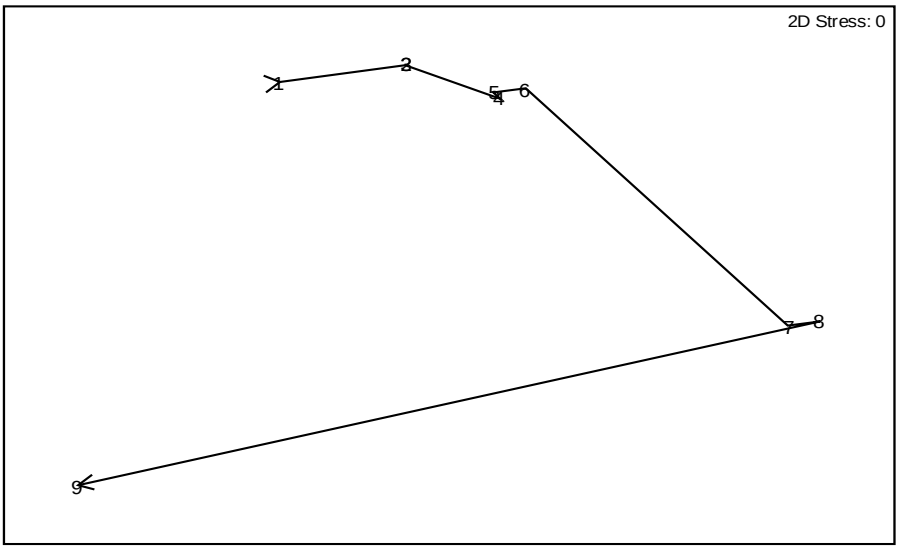


Figure 11. Seriation of fouling communities growing on the rebar of trap 9, located at the inshore, near-reef site. The numbers indicate months 1-9. This trap was lost and recovered after Hurricane Earl.

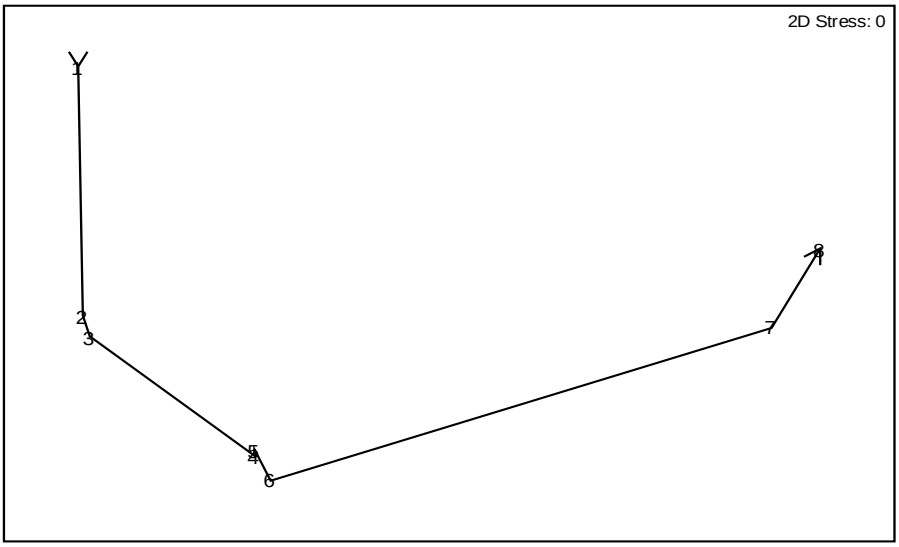


Figure 12. Seriation of fouling communities excluding the effects of Hurricane Earl, growing on the rebar of trap 9, located at the inshore, near-reef site. The numbers indicate months 1-8.

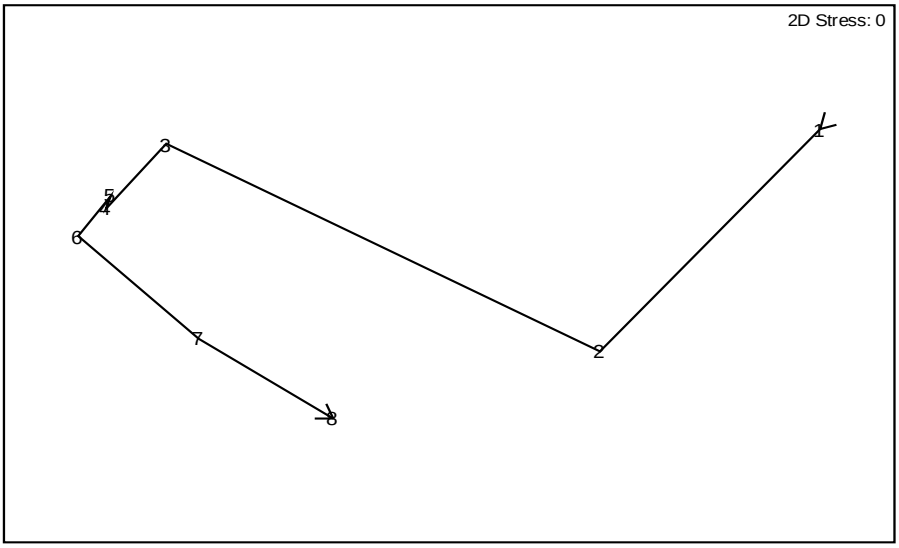


Figure 13. Seriation of fouling communities growing on the rebar of trap 10, located at the inshore, far-reef site. The numbers indicate months 1-8. This trap was lost during Hurricane Earl and not recovered.

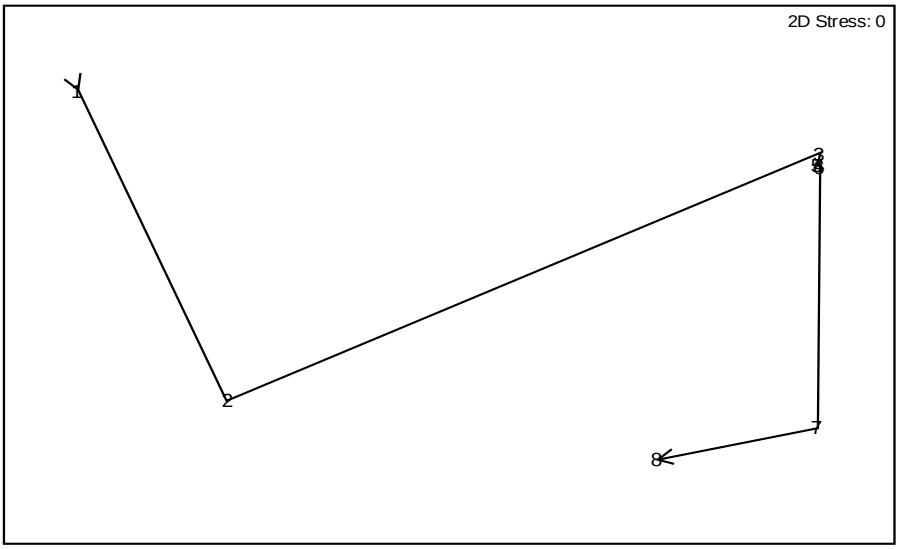
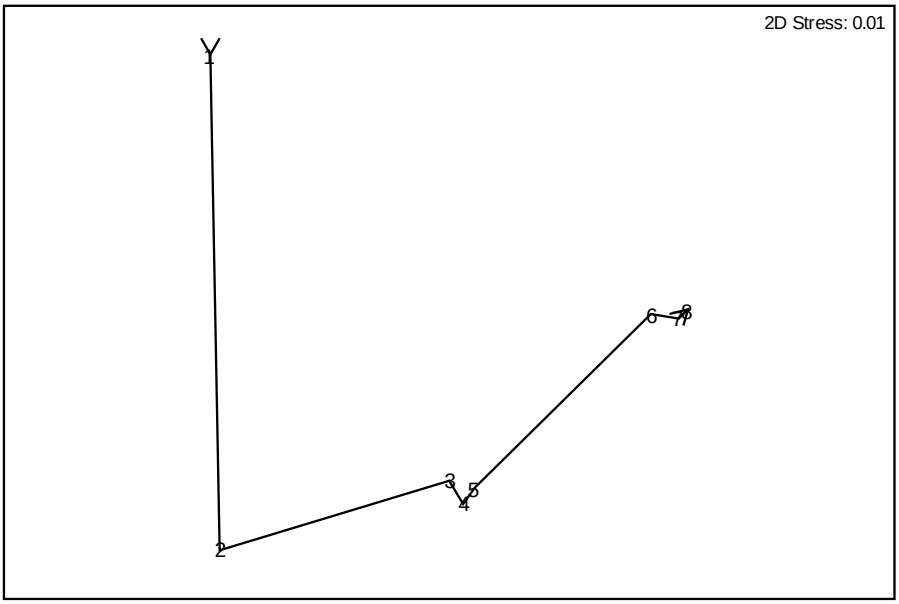


Figure 14. Seriation of fouling communities growing on the rebar of trap 11, located at the inshore, far-reef site. The numbers indicate months 1-8. This trap was lost during Hurricane Earl and not recovered.



Figurw 15. Seriation of fouling communities growing on the rebar of trap 12, located at the inshore, far-reef site. The numbers indicate months 1-8. This trap was lost during Hurricane Earl and not recovered.