

CAPACITY BUILDING

MARINE HABITAT MAPS & SURVEYS

WATER QUALITY SURVEYS

FISHERIES SOCIAL SURVEYS

PROJECT PARTICIPATION

reefmap Nicaragua




2003

CORN ISLANDS AND PEARL CAYS

PROJECT REPORT




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EXECUTIVE SUMMARY

1. OVERVIEW

This report presents the results and findings of the reefmap project, a multidisciplinary study focussing on coastal environmental issues in the Corn Islands, Nicaragua. The reefmap project was initiated by a team from the Tropical Coastal Management programme at the University of Newcastle upon Tyne, UK. The aim of the project was to gather information to support local government and national agencies in their efforts to promote sustainable management of natural resources and the environment in the Corn Islands, Nicaragua. The project was funded through grants from several different institutions, both international and Nicaraguan, and the generous contributions from enterprises and private persons in The Corn Islands and in the UK.

The field work period of the project was carried out in May and June 2003 with the support and collaboration of the Municipal Government of Corn Islands, the Ministry of Natural Resources and Environment (MARENA), the National Fisheries Administration (AdPesca), the Bluefields Indian Caribbean University (BICU), the University of the Autonomous Regions of the Caribbean Coast of Nicaragua (URACCAN), the Movement for the Defence and Dignity of Corn Islands, and Dr Bob Foster Smith from Envision Mapping, based at the University of Newcastle upon Tyne. The project was focused around six studies:

► **Fisheries social structures and perceptions study:** conducting interview surveys with artisanal fishers to examine perceptions towards management interventions, and social factors influencing the potential for co-management.

► **Fisheries spatial and economic study:** conducting interview surveys to analyse the spatial distribution and microeconomics of the artisanal fisheries.

► **Marine habitat mapping:** using RoxAnn acoustic survey and satellite image analysis to create maps of the marine habitats surrounding the Corn Islands.

► **Coral reef surveys:** applying the Atlantic Gulf Rapid Reef Assessment (AGRRA) protocol for surveying reef species and health.

► **Water quality survey:** taking water samples for chemical analysis from wetlands and conducting an interview survey of local perceptions of pollution and water quality on Great Corn Island.

► **Marine sedimentation study:** taking sediment samples along a gradient from the main land to Pearl Cays to Corn Islands, and comparing these samples with results from coral reef composition video surveys along the same gradient.

A training element was integrated into the project, with staff and students from the universities URACCAN and BICU, as well as members from the Movement for the Defence and Dignity of Corn Islands, learning scientific fieldwork methodologies through participation. The project aimed to involve the local community and had meetings with representatives of local civil society organisations, held lectures in schools and discussed the preliminary results of the project at a workshop and a public meeting.

2. FINDINGS AND CONCLUSIONS

2.1. FISHERIES SOCIAL STRUCTURES AND PERCEPTIONS STUDY

A majority of the artisanal fishers feel that foreign-owned industrial boats are to blame for the decline in the fisheries. The main part of the fishers think that it is the responsibility of the national government to ensure that lobster stocks recovery, while half of the fishers see themselves as responsible. The fisher community is grouped mainly by fishing technique and ethnicity. The community as a whole was found to be more or less homogenous in its perceptions of the management of the fisheries but for a few exceptions. Those who fish with traps are generally more positive to a proposed closed area (probably because they not fish in the proposed area), are more inclined to see diving as one of the reasons for the decline of lobster catches, and would like a ban on diving. The general consensus and positive attitudes towards existing and proposed management interventions shows a good potential for co-management, but the issue of diving and its linkage to conflicts between different ethnic groups in the community, could pose an obstacle to collaboration. A lack of organisation and leadership in the fisher community presents a barrier towards fisher participation in management, but successful management initiatives in Little Corn Island may provide a role model.

2.2. FISHERIES SPATIAL AND ECONOMIC STUDY

Artisanal fisheries extend over 50 km off corn Islands to the north. Lobster fishing is more intensive north and west of the islands. Trap fishing effort was highly aggregated while diving had a regular dispersion. This may have been due to the scale at which it was examined. Daily lobster catches by individual divers increased significantly with fuel expenditure ($p<0.05$) at a rate that would more than compensate for increased fuel expenditure while maximum catches stated by trap fishers also showed a positive relationship with distance from the islands ($p = 0.002$). Fishers may not perceive these positive trends in catch rate with distance due to considerable variability in catches. They may also take account of other costs of travelling further, which constrain the size of their resource space.

2.3. MARINE HABITAT MAPPING

The marine habitat maps of Corn Islands were produced by using a combination of RoxAnn Acoustic Discrimination System data and Landsat TM imagery analysis. They can be found on pages 60-70 in this report. The resulting maps still require an accuracy assessment before they are used for management purposes but they represent a considerable step towards supporting well planned management of the islands inshore marine resources. They will allow decision makers to take informed decisions, identify important and vulnerable habitats, and to develop policies and plans to protect and conserve these areas. They may be used as a basemap for a geographic information system, as an educational resource and may be used to support funding bids to develop a well designed and long-term research programme for the islands marine and coastal resources. In addition to the habitat maps themselves, extensive literature reviews were combined with a local [perceptions] assessment of the value and threats to each habitat class in the maps. These habitat assessments provided a framework for habitat specific policy and research recommendations, which will hopefully support a strategic and targeted approach to coastal management on the islands.

2.4. CORAL REEF SURVEYS

Variability in reef condition between sites was high according to a number of structurally or functionally important benthic indicators, such as coral size-frequency distributions, percent mortality and presence of disease. Shallow exposed sites appear to have undergone a community phase shift as a result of the loss of the major reef-building coral *Acropora palmata*. Whereas deeper sites on the outer reefs of Great Corn Island seem to be suffering from a combination of white plague disease and macroalgal overgrowth possibly as a result of decreased herbivory. However, a long-term monitoring programme incorporating temporally explicit data in addition to spatially explicit data would be required to reveal the presence of human influences on the reefs such as nutrient pollution. The information provided by the present study provides a snapshot of reef health at selected sites around the Corn Islands and may prove useful as baseline data upon which to build a monitoring programme following the same methodology. The study also represents one of the first quantitative investigation of reef health to be conducted in Nicaragua and the data will be included in the AGRRA (http://www.coral.noaa.gov/agra/) regional database for the wider Caribbean region.

2.5. WETLAND WATER QUALITY STUDY

Water samples from of Great Corn Island shows that wetlands located on the western side of Great Corn Island presented a lesser water quality. The perceptions survey revealed that a majority of respondents thought that the condition of the wetlands had worsened over the last ten years. North End and Loma were the areas perceived as having undergone the most negative change. The most frequently mentioned causes of pollution were garbage, sewage and dead animals. The western side of the island was perceived as the most affected by pollution in regard to near-shore waters, especially the area around Brig Bay. Hydrocarbons and garbage were perceived as the major causes of pollution in coastal waters. Overpopulation and lack of water treatment on the western side of the island was suggested to make it more exposed to pollution. The condition of the island’s wetlands was ranked highly as a reason for preoccupation. The most effective ways of reducing pollution was perceived to be a better waste water treatment, while stricter laws came second. The community-based pollution perceptions study proved to be a cost-effective way of supporting the definition of priorities for management interventions.

2.6. MARINE SEDIMENTATION STUDY

The site most affected by terrigenous sedimentation was found to be the most diverse. This inshore site showed sedimentation quality to be largely related to terrigenous influence, with offshore sites influenced mainly by reef sediment. Strong correlations were found between abundance of sedimentation-tolerant species of scleractinian coral and the terrigenous acid insoluble non-calcareous sediment fractions. Similarly, there was a significant decrease in the ratio of *Porites astreoides* brown to green colour morphs along the decreasing gradient of terrestrial influence. From a management perspective, a more complete approach to sedimentation studies is required, based on sedimentation quality, timing and quantity.

3. MANAGEMENT RECOMMENDATIONS IN BRIEF

3.1. FISHERIES

► There is a serious need for further investigation of the ecology and life cycle of the Nicaraguan spiny lobster populations. Studies should integrate local fisher knowledge.

► Fishing effort could be monitored by installation of satellite vessel monitoring systems (VMS) on all industrial boats.

► Frequent and random controls of catches at the artisanal landing sites could make it more difficult for the fishers to trade in small and spawning lobster. In order to minimise the market for small and spawning lobster, authorities should form a partnership with restaurants and hotels on the islands and other parts of the country.

► A centralised scheme for getting traps out of the water for the closed season should be organised, possibly renting an industrial boat for the job to fetch all artisanal traps.

► Research should be conducted in collaboration with the fishers on the effect of traps and diving on substrate.

► A potential ban on diving would require a large-scale participative study into the effects of such an intervention on the livelihoods of the divers and their families and should be implemented on a longer time-scale with a gradual phase-out.

► Comparative studies should be undertaken examining the efficiency of different fishing techniques and determining the impact of improved navigational techniques on the pressure on and range of fishing areas, with results feeding in fisheries models. Based on these studies, guidelines should be set up for trap design.

► A forum for dialogue and cooperation between fishers, fisheries companies and authorities should be set up to discuss more effective implementation and enforcement of regulations. This should be facilitated by a task force working for the organisation of the fishers and fisher participation in management. A participatory research process should be initiated on the islands to support the task force with information to assist conflict management.

► The planning of a potential MPA should involve a full-scale assessment programme looking into socio-economic, legal and ecological aspects of the implementation of the MPA. It should strive to involve all affected stakeholders in research, planning, decision-making, implementation, and monitoring and evaluation.

3.2. ECOSYSTEMS RESEARCH AND MONITORING NEEDS

► In order to prevent an ecological coral reef-algal phase shift, a monitoring system should be put in place to monitor and manage levels of inshore exploitation of fish, and coastal pollution should be monitored and controlled.

► Costal pollution input could be reduced through waste management planning and through guidance on appropriate technologies, for example affordable and small scale waste treatment for pit latrines or centralised waste treatment. Communities should be educated about the how to dispose of different wastes in a way that minimises the environmental impact. Private waste reuse and recycling and management enterprises should be encouraged.

► The application of tools such as sensitivity mapping, development planning and environmental impact assessment should prevent development encroachment that threatens the ecological integrity of critical coastal ecosystems. All new larger developments should be required to provide a comprehensive review of how they will deal with waste disposal and provide developers with guidance on waste management and soil conservation practices.

► A long term participatory waste and pollution monitoring system should be set up.

RESUMEN EJECUTIVO

1. DESCRIPCIÓN GENERAL

Este informe presenta los resultados del proyecto reefmap, un estudio multidisciplinario que orientado a los asuntos ambientales costeras en Corn Islands (las Islas del Maíz), Nicaragua. El proyecto reefmap fue iniciado por un equipo del programa de Manejo de Manejo de Costas Tropicales de la Universidad de Newcastle upon Tyne, Reino Unido. El propósito del proyecto era recopilar información científico para apoyar al gobierno local y a las agencias nacionales en sus esfuerzos de promover el manejo sostenible de los recursos naturales y el ambiente en las islas del maíz, Nicaragua. El proyecto fue financiado con concesiones de varias diversas instituciones internacionales y nicaragüenses, y con las contribuciones generosas de empresas y personas privadas en Corn Islands y en el Reino Unido.

El período del trabajo en campo del proyecto fue realizado en mayo y junio de 2003 con la ayuda y la colaboración del Gobierno Municipal de Corn Islands, el Ministerio del Ambiente y los Recursos Naturales (MARENA), la Administración Pesquero (AdPesca), la Universidad Indígena y Caribeña de Bluefields (BICU), la Universidad de las Regiones Autónomas de la Costa Caribe de Nicaragua (URACCAN), el Movimiento para la Defensa y Dignidad de Corn Islands, y el Dr. Bob Foster Smith de Envision Mapping, basado en la Universidad de Newcastle upon Tyne. El proyecto fue estructurado alrededor de seis estudios:

► **Estructuras sociales y las opiniones en la comunidad pesquero:** conduciendo encuestas con los pescadores artesanales para examinar sus opiniones hacia las intervenciones manéjales, y los factores sociales que influencian la potencial para el co-manejo.

► **Estudio económico/espacial de la pesca:** conduciendo encuestas con los pescadores de Corn Islands para analizar la distribución espacial y el micro-economía de la pesca artesanal.

► **Mapeo de los hábitats marinos:** analizando datos acústicas RoxAnn e imágenes del satélite para crear mapas de los hábitats marinos que rodean Corn Islands.

► **Evaluación de los arrecifes coralinos:** aplicación del protocolo de Evaluación Rápido de los Arrecifes Coralinos del Golfo Atlántico (AGRRA) para examinar las especies y la salud de los arrecifes coralinos de Corn Islands.

► **Calidad del agua de los suampos:** analizando químicamente muestras de agua de los suampos, y conduciendo una encuesta sobre las opiniones locales de la contaminación y la calidad del agua en la isla grande de Corn Islands.

► **Sedimentación marina:** tomando muestras de sedimento a lo largo de un gradiente de la costa hasta Pearl Cays y Corn Islands, comparando estas muestras con resultados de investigaciones de vídeo sobre la composición de los arrecifes coralinos a lo largo del mismo gradiente.

Un elemento de entrenamiento fue integrado en el proyecto, personal y estudiantes de las universidades URACCAN y BICU, así como miembros del Movimiento para la Defensa y Dignidad de Corn Islands, fueron capacitados en metodologías científicas del campo. El proyecto pretendía implicar a la comunidad local y tenía reuniones con representantes de organizaciones civiles locales, llevó a cabo conferencias en escuelas, y organizó un taller y una reunión pública para discutir los resultados preliminares del proyecto.

2. RESULTADOS Y CONCLUSIONES

2.1. ESTRUCTURAS SOCIALES Y OPINIONES EN LA COMUNIDAD PESQUERO

Una mayoría de los pescadores artesanales piensan que los barcos industriales de propiedad extranjero tienen la culpa principal por el decaimiento pesquero. La gran parte de los pesqueros piensan que es la responsabilidad del gobierno nacional de asegurar recuperación de la langosta, mientras que la mitad de los pescadores se considera como responsables ellos mismos. La comunidad pesquero es agrupada principalmente según técnica y pertenencia étnica. La comunidad en su totalidad se encontró más o menos homogénea en relación con sus opiniones sobre el manejo pesquero con algunas excepciones. Los que pescan con nasas son generalmente más positivos a un área cerrada propuesta (probablemente porque no pescan en el área propuesta), están más inclinados a ver el buceo como una de las razones por el decaimiento en las capturas de langosta, y quisieran una prohibición del buceo. El consenso general y las actitudes positivas hacia intervenciones de manejo existentes y propuestos, demuestra un buen potencial para el co-manejo, pero el asunto del buceo y su acoplamiento a conflictos entre diversos grupos étnicos en la comunidad, podría plantear un obstáculo por la colaboración. Una carencia de la organización y de la dirección en la comunidad del pescador presenta una barrera hacia la participación del pescador en la gerencia, pero las iniciativas acertadas de la gerencia en la pequeña isla del maíz pueden proporcionar un modelo del papel.

2.2. ESTUDIO ECONÓMICO/ESPACIAL DE LA PESCA

La pesca artesanal se extiende hasta más que 50 kilómetros al norte de Corn Islands. La pesca de langosta es más intensiva al norte y al oeste de las islas. El esfuerzo de pesca con nansas fue altamente agregado, mientras el buceo tenía una dispersión regular. Esto pudo haber sido debido a la escala en la cual fue examinada. Las capturas diarios de langosta de los buzos individuales crece significativamente con el gasto del combustible ($p<0.05$), en una tasa que más que compensaría el gasto creciente del combustible, mientras que las capturas máximas indicados por los pescadores de nasas también demostraron una relación positiva con la distancia de las islas ($p = 0.002$). Puede ser que los pescadores no percibieren estas tendencias positivas en tasa de captura con la distancia debido a la variabilidad considerable en capturas. Además, los pescadores podrían tomar cuenta de otros costos de viajar más lejos, que limitan el tamaño de su espacio de recurso.

2.3. MAPEO DE LOS HABITATS MARINOS

Los mapas de los hábitats marinos fueron producidos usando una combinación de datos del RoxAnn, un sistema de discriminación acústica, y de datos de las imágenes de Landsat TM. Se encuentran en las páginas 60-70 de este informe. Los mapas que todavía requieren un evaluación de exactitud antes de que se utilicen para los propósitos del manejo pero representan un paso considerable para apoyar al manejo bien planificado de los recursos marinas costeros de las islas. Permitirán a los políticos de tomar decisiones informadas, identificar los hábitats importantes y vulnerables, y desarrollar políticas y planes para proteger y para conservar estas áreas. Pueden ser utilizados como mapa de base para un sistema de información geográfico (SIG), como recurso educativo, y pueden ser utilizados para apoyar solicitudes de financiamiento para desarrollar un programa de investigación bien diseñado y de largo plazo para las islas marinas y los recursos costeros. Adicionalmente, las revisiones extensas de la literatura fueron combinadas con un encuestas locales [de percepciones] sobre el valor de y las amenazas a cada hábitat clasificado en los mapas. Estas evaluaciones de los hábitats proporcionaron un marco para recomendaciones de manejo y de investigación específicas, que esperanzadamente apoyarán a un método estratégico y apuntado en el manejo costera en las islas.

2.4. EVALUACION DE LOS ARRECIFES CORALLINOS

La variabilidad en la condición del arrecife entre los sitios era alta según algunas de indicadores bénticos estructuralmente o funcionalmente importantes, tales como las distribuciones coralinas de tamaño-frecuencia, el por ciento mortalidad y la presencia de enfermedad. Los sitios expuestos poco profundos aparecen haber experimentado un desplazamiento de fase en la comunidad como resultado de la pérdida del coral principal de construcción de arrecife, el *Acropora palmata*. Mientras que los sitios más profundos en los arrecifes exteriores de Great Corn Island se parecen sufrir de una combinación de la enfermedad la plaga blanca y del crecimiento excesivo de macroalgas posiblemente como resultado de herbivoria disminuida. Sin embargo, un programa de supervisión a largo plazo que incorpora datos temporalmente explícitos, además que datos espaciales explícitos sería requerido para revelar la presencia de influencias humanas a los arrecifes tales como contaminación de nutrientes. La información proporcionada por el estudio actual proporciona una foto instantáneo de la salud de los arrecifes en puntos determinados alrededor de Corn Islands y puede ser útil como un base sobre lo cual se podría construir un programa de monitoreo siguiendo la misma metodología de evaluación. El estudio representa uno de las primeras investigaciones cuantitativas de la salud de los arrecifes coralinos en Nicaragua y los datos serán incluidos en la base de datos regional de AGRRA (http://www.coral.noaa.gov/agra/) para la región del Caribe.

2.5. CALIDAD DE AGUA DE LOS SUAMPOS

Muestras de agua de Great Corn Island demuestran que los suampos situados en el oeste presentaron una calidad peor de agua. La encuesta de percepciones revelaba que una mayoría de respondedores pensaron que la condición de los suampos se había empeorado durante los diez años pasados. North End y Loma eran las áreas percibidas como siendo experimentado el cambio más negativo. Las causas posibles de contaminación mencionadas lo más frecuentemente eran basura, aguas residuales y animales muertos. El parte occidental de la Isla se percibía como lo más afectado de contaminación en vista de aguas marinos cerca la costa, especialmente el área alrededor de Brig Bay. Hidrocarburos y la basura eran percibidos como las causas principales de la contaminación en aguas costeras. La superpoblación y la carencia del tratamiento de aguas en el lado occidental de la Isla fueron sugeridas como razones de la exposición mayor la contaminación. La condición de los suampos de la isla se ponía en un rango alto como una razón de preocupación. Las maneras más eficaces de reducir la contaminación fueron percibidas para ser un tratamiento mejor de aguas residuales, mientras que la legislación más estricta se ponía en segundo lugar. La encuesta de percepciones basado en la comunidad de la contaminación se demostraba ser una manera rentable e efectivo de apoyar en la definición de prioridades para los intervenciones de manejo.

2.6. SEDIMENTACIÓN MARINA

El sitio lo más afectado por la sedimentación terrígena fue encontrado de ser lo más diverso. Este sitio costero demostró la calidad de sedimentación que se relacionará en gran parte con la influencia terrígena, mientras los sitios más afuera de la costa eran influenciados principalmente por sedimento de arrecifes. Fuertes correlaciones fueron encontradas entre la abundancia de especies del coral scleractinia que son tolerantes al sedimentación y las fracciones de sedimentos terrígenas non-calcáreo insolubles ácidas. Similarmente, había una disminución significativa del fracción de morfos del color bronceo sobre los verdes de *Porites asteroides* a lo largo de un gradiente de influencia terrestre disminuyendo. De una perspectiva de manejo, un acercamiento más completo a estudios de sedimentación se requiere, basado en calidad de la sedimentación, la sincronización temporal y la cantidad.

3. RECOMENDACIONES PARA EL MANEJO EN BREVE

3.1. LA PESCA

► Hay una necesidad seria de la investigación adicional de la ecología y del ciclo de vida de las poblaciones nicaragüenses de langosta. Los estudios deben integrar el conocimiento local de los pescadores.

► Se puede supervisar el esfuerzo pesquero por la instalación de los sistemas de supervisión de satélites (VMS) en todos los barcos industriales.

► Controles frecuentes y al azar de capturas en los acopios artesanales podían hacerlo más difícil para que los pescadores negocien en langosta pequeña y con huevos. Para reducir al mínimo el mercado para la langosta pequeña y con huevos, las autoridades deben formar una coordinarse con los restaurantes y los hoteles en las islas y en otras partes del país.

► Se debe organizar un esquema centralizado para conseguir nasas del mar para la veda, posiblemente alquilando un barco industrial para traer todas las trampas del artisanal.

► Se debe conducir la investigación en colaboración con los pescadores sobre el efecto de nasas y el buceo sobre el substrato.

► Una interdicción potencial del buceo requeriría un estudio participativo en grande escala sobre los efectos de tal intervención a los sustentos de los buzos y sus familias y se debe poner en ejecución en un escala de tiempo más largo con un eliminación gradual.

► Se deben iniciar estudios comparativos examinando la eficacia de diversas técnicas de la pesca y determinando el impacto de técnicas de navegación mejoradas en el esfuerzo pesquero en y la gama de las zonas pesqueras, usando los resultados en los modelos de la ecología pesquero. Basado en estos estudios, se debe instalar reglamentos para el diseño de nasas.

► Se debe iniciar un proyecto de investigación para evaluar los efectos a gran escala de la pesca de peces en los ecosistemas costeros, y se debe instalar un sistema para el monitoreo capturas y el esfuerzo pesquero cambiando de peces.

► Se debe instalar un foro para el diálogo y la cooperación entre los pescadores, las compañías y las industrias pesqueras, y las autoridades para discutir una puesta en práctica y una aplicación más eficaz de los regulaciones. Se debe facilitar esto por un grupo de acción que trabajaría con la organización de los pescadores y la participación de los pescadores en manejo. Se debe iniciar un proceso de investigación participativo en las islas para apoyar el grupo de acción con la información para asistir al manejo de los conflictos potenciales.

► El planeamiento de un área protegida marina (APM) potencial debe implicar un programa de evaluación completa que investiga los aspectos socioeconómicos, legales y ecológicos de la puesta en práctica del APM. Debe implicar a todos los actores afectados del APM en la investigación, el planeamiento, la toma de decisión, la puesta en práctica, y la supervisión y la evaluación del APM.

3.2. INVESTIGACION Y MONITOREO DE ECOSISTEMAS

► Para prevenir un desplazamiento de fase ecológico de arrecife hacia algas, un sistema de supervisión debe ser puesto en lugar para el monitoreo y el manejo de los niveles de la explotación costera de pescados, y la contaminación costera debe ser monitoreado y controlada.

► Se podía reducir la contaminación costal con un planeamiento de manejo de desechos y con apoyo de tecnologías apropiadas, por ejemplo tratamiento de pequeña escala barato o el tratamiento centralizado. Las comunidades deben ser capacitadas sobre cómo disponer de diversas basuras de una manera que reduzca al mínimo las consecuencias para el medio ambiente. Empresas privadas de la reutilización y del reciclaje deben ser apoyadas.

► El uso de herramientas tales como el mapeo de sensibilidad, el planeamiento de desarrollo y la evaluación de impactos al medio ambiente debe prevenir la usurpación del desarrollo que amenaza la integridad ecológica de ecosistemas costeros sensibles. Todos los proyectos de desarrollo grandes se deben requerir una revisiones comprensivas de cómo se ocuparán de la disposición de desechos y se debe proveer a los reveladores la dirección prácticas de la conservación del suelo y el manejo de desechos.

► Se debe establecer una sistema participativo de monitoreo de basura y contaminación a largo plazo.

INTRODUCTION

1. THE REEFMAP PROJECT

The Reefmap Project was initiated by Duncan Hume in the summer of 2002 after a brief visit to the Corn Islands and subsequent conversations with an American ecologist Joseph Ryan. Joe has worked extensively on the Atlantic coast of Nicaragua, previously working with British expeditions to survey Great Corn's coral reefs and now works in Nicaragua advising the government on marine and coastal management issues. The initial project idea was to map the islands coral reefs (hence the name reefmap) this initial idea developed as a result of inspiration and contacts provided through the MSc course in Tropical Coastal Management at the University of Newcastle. Together, a group of six students on the program (Fig. 1) felt that their individual end-of-year dissertations could be integrated to provide a suite of information for a chosen coastal area in the developing tropics. To develop a more holistic and integrated project overview it was decided that each student project would focus upon a different issue in the coastal zone of the study area in close collaboration with local partners. With the help of a professional photographer and cameraman, the team aimed to work with host country organisations in collecting data, which supported existing coastal management efforts. In addition the outcomes were to be used to create multimedia educational resources, which are to be used both in the UK and in the host country. The development of such an initiative required considerable efforts from the project team to ensure that the required funding was raised, the essential host-country collaboration was organised and the necessary logistical arrangements were finalized before departing for Nicaragua. With the generous contributions of the sponsors and aid of the project patrons a total of over £20,000 was raised to support the work in this report and the associated CD ROM and some huge contributions of time and effort from within Nicaragua and the UK ensured the completion of the projects aims.

Figure 1 - The UK-based part of the project team: clockwise from the far right: Randolph Velterop (sedimentation study), Clare Drakeford (dive leader), Tim Daw (fisheries spatial study), Marie-Caroline Badjeck (wetland water quality study), Marcos Clowes (dive assistant), Phil Broadhurst (cameraman), Alex Hunt (coral surveys), Ulrika Gunnartz (fisheries social study) and Duncan Hume (marine habitat mapping).

2. THE PROJECT SITE

The chosen location for the Reefmap Project was a pair of small inhabited islands on the vast Caribbean coastal shelf of Nicaragua known as the Corn Islands or Las Islas de Maiz (Fig. 2).

The islands are volcanic in origin and are situated 68 km from the mainland. The larger of the two islands, Great Corn Island, has a population of over 7000 and is just 5km long from the North to the South, covering an area of 10.3km^2. Little Corn Island is located 15 km to the northeast of Great Corn Island and is just one half the size with around a quarter of the population. The islands are characterized by a wide variety of ecosystems with the presence of wetlands and numerous species of mangroves as well as coral reefs on the northern shore. The climate is humid tropical with an average monthly rainfall of 50 mm, and the highest rainfall (150-300mm) occurring between July and December. The mean annual temperature is 27°C (10°C seasonal range), with prevailing winds from the northeast.

An ethnic mix of Creole, Mestizo and Miskitu (an indigenous people originating from the Northern part of the Nicaraguan Caribbean coast) populates the islands, and Creole English, Spanish and Miskitu are spoken, while Spanish is the official language of Nicaragua and dominates as the written language. Until 1988, the main source of income for the islanders was light processing of coconuts and seafood, lobster in particular. However, in 1988 Hurricane Joan struck a devastating blow to the islands, destroying the majority of the coconut trees and thereby this industry. The fishing industry has since become the main source of income, and over 40% (in terms of value) of Nicaragua's total seafood exports are now landed and processed in Corn Islands. In light of a recent dramatic decrease in the lobster stocks, the municipal and central government are now actively promoting tourism in the region in order to diversify the island economy and reduce its reliance on the fisheries. With an annual population growth estimated at 3.9% and significant seasonal population movements, the development of tourism will inevitably bring additional pressure on the islands' natural environment.

Figure 2: Map of the Western Caribbean region showing the location of the Corn Islands on the Atlantic coastal shelf of Nicaragua.

Population growth has already led to increased urbanization on the island, particularly in the Brig Bay area on the western side of the island, where 65% of the population is located. The increased competition for natural resources and land has lead to conflicts between different groups in the community, and has created polarisation between long term resident inhabitants and migrant fishermen. Both reefs and mangrove swamps are being threatened by this development; near shore corals are feared to be in decline due to subterranean discharges of sewage contaminated groundwater originating from the island, and mangroves are being used as dumpsites for domestic waste, as well as being threatened by tourism development and construction. Add to this the threat of increasing storm frequency and intensity and sea level rise as a result of global climate change and there are a wide range of issues that warranted further investigation on the Corn Islands.

The reefmap project was divided into three parts (each chapter of the report covers one aspect):

1. Surveys of the Islands' Fishery (the most important economic activity),
2. Mapping and Surveying of the islands coastal habitats (the most important resources) and
3. Surveys of Environmental Quality (to identify some of the most significant threats)

The project also aimed to produce information in a format useful for management and education. To this end all of the projects data has been incorporated into a database and the spatial information has been included as GIS layers. These data sources are included on the accompanying CD ROM along with a professionally produced documentary outlining the projects aims and successes.

CONTRIBUTORS AND ACKNOWLEDGEMENTS

1. IMPORTANCE OF LOCAL INVOLVEMENT

The success of projects like Reefmap Nicaragua is highly dependant upon the level of community involvement. Without community support, even the most rigorously devised coastal management strategy has the potential to fail, and since our goal is to aid the production of an effective plan for the Corn Islands it was essential that the local community was involved from the very beginning.

To ensure local participation, contacts with governmental, non-governmental and academic institutions were made at an early stage. Response was overwhelmingly positive and project plans were developed in close dialogue with the Nicaraguan Ministry of Environment (MARENA), the National Fisheries Administration (AdPesca) the Bluefields Indian and Caribbean University (BICU), The University of the Autonomous Atlantic Region of Nicaragua (URACCAN), the Municipality of Corn Islands and local NGOs. Beginning the fieldwork period, interaction with the local community was fostered by living with community members and sharing their lifestyle. Individuals and some local businesses also contributed with in-kind donations and support to the project. The output of this wide variety of host country involvement resulted in an array of activities and outputs.

2. COLLABORATION WITH THE CENTRAL GOVERNMENT

Contact with the Ministry of Environment (MARENA) was established early on in the project and support was sought and obtained from Liza Gonzales, Director of the Biodiversity & Protected Areas department. MARENA has shown a great interest in the results of the Reefmap studies, hoping to use them in future natural resource management plans in the region.

The National Fisheries Administration (ADPESCA) gave substantial support to the project by providing background information for the fisheries studies. AdPesca is currently battling problems with enforcement of regulations designed to protect stocks and ensure sustainable use of fisheries resources. The results from the Reefmap project support the current effort to reform and strengthen management of small-scale fisheries in the Corn Islands.

At the end of the fieldwork period, meetings were held with representatives from both MARENA and ADPESCA to discuss the preliminary results of the project and following this final report, further discussion with both institutions will ensue in order to provide a functional output.

3. INVOLVEMENT OF LOCAL UNIVERSITIES AND EXPERTISE

One of the main objectives of the study was to develop capacity within the region for the continuation of research and monitoring. The participation of staff and students from Bluefields Indian and Caribbean University (BICU) (Fig. 1) and The University of the Autonomous Atlantic Region of Nicaragua (URACCAN) was sought to allow students and staff the opportunity to gain practical experience in a wide variety of research techniques. The team was also fortunate to be assisted by Yamil Zapata, a marine biologist from Puerto Cabezas (the main town of the Northern Atlantic Region) with previous experience of coral reef research in the Corn Islands. The participation of these counterparts would not have been possible without generous and timely assistance from RAAN-Asdi-RAAS; a local NGO who are gratefully acknowledged along with the project's other supporters. The specifics of the University collaboration are summarised next.

Figure 1 - Alvaro Segura, a fish Biologist from Costa Rica who assisted the coral reef surveys, in front of the BICU facilities in Great Corn Island.

4. STUDENT PARTICIPATION - URACCAN

A class of eight students from the programme in Fisheries Engineering at URACCAN (Gary Gomez, Melvin Archibold, Nora Figueroa, Elizabeth Pena, Carton Moses, Leard Thomas, Noel Cash and Bismarck Granados) joined the project on the Corn Islands from 4^{th}-9^{th} June for a field trip together with their lecturer Karen Joseph. Their time was split between conducting a survey of fishing households on Corn Island, providing data for the two fisheries studies, and a survey of fish landings. They were introduced to the basics of planning and executing social surveys for fisheries management planning, and how to obtain representative samples of catches and record biological data from fish landing. The students also took a tour round the factory of PASENIC and gained experience of working with an Access database to organise and store data. The data on fish landings was used by Karen Joseph to conduct a data analysis tutorial on return to URACCAN.

One graduate student (Clarence Gonzales) stayed with the project throughout the whole field period. In order to gain interdisciplinary field experiences preparing him for his master he participated in all the projects. He worked with a RoxAnn acoustic ground discrimination system and acoustic survey techniques and spent some time working with MapInfo (GIS) undertaking preliminary analysis of the datasets. He also assisted with the organisation of the URACCAN field trip and the spatial and economic study of the islands fisheries. By participating in the fisheries studies he gained experience in analysis of socio-economic and biological data and its incorporation into a GIS system using MapInfo software. He took part in the project's public presentation in Brig Bay presenting preliminary results from the study.

5. STUDENT PARTICIPATION - BICU

One student from the Programme of Marine Ecology in Bluefields (Marlon Alfaro Dublón) and three from the programme of Tourist Administration in Corn Island participated in the water quality study during the full extent of the fieldwork period (Gary Archibald, Adalia White and Ebony García). The students were involved in the collection of water samples and trained in the use of LaMotte test kits. The students were also involved in the elaboration of questionnaires and execution of interviews for a perception study. They were trained in social survey methodology and the survey was conducted in both English and Spanish with their assistance. They also conducted talks in primary and secondary schools on the importance of the environment and introducing students to the kind of work they were undertaking. They were involved in the elaboration of the workshop held at the BICU Corn Island, where they presented the water quality study to a variety of stakeholders and discussed the results and implications. These activities gave them experience in public speech and environmental education outreach activities.

One student from the Programme in Marine Ecology at BICU in Bluefields (Jessenia Bello) participated in the study "Social Implications of the artisanal fisheries of Corn Islands". She was involved in planning the fieldwork, elaborating questionnaires and collecting data. She worked with two different questionnaires, undertaking interviews with fishermen from both Little and Great Corn Island. She also participated in a lecture on marine environment for pupils at the Corn Island Baptist School, and worked with the preparation of a public meeting and a workshop presenting and discussing the studies of the Reefmap project. By participating in the project she gained practical experience in how to plan, structure and execute a social science study. She increased her general knowledge of the ecology and economy of the fisheries of the Atlantic Coast of Nicaragua. She has also learned the importance of, and some basic conduct for dissemination of scientific information to involved stakeholders and to the public.

Two students from the Programme of Marine Ecology at BICU in Bluefields (Ivette Wilson and Dwayne Montealban) participated in the marine ecological surveys of the Corn Islands, along with their supervisor (Eduardo Sieu), (Fig. 2). They earned a PADI Open Water Certification from Dive Little Corn and received instruction in species identification and reef survey techniques before conducting daily field studies on both islands from the 18th of May to the 25th of June. They collected detailed survey data whilst using SCUBA equipment, and entered the information into the Reefmap Database. By participating in the study they gained experience in planning and conducting marine surveys, investigating coral reef species composition and health & Access databases.

Figure 2 - Ivette Wilson, one of two students from BICU who were trained, on her way out to survey the reefs off Great Corn Island.

One student from the Marine Ecology Programme (Ernie Atily) worked with the initial field surveys collecting data using a RoxAnn acoustic ground discrimination system. He collected 'ground truth data' which is used for the classification of the marine habitat maps and assisted with preliminary analysis of the data in the MapInfo GIS. He also worked with Phil Broadhurst, the project photographer and web designer to put together a preliminary website for FARENA (the BICU Faculty of Biology) gaining skills in web design.

6. COLLABORATION WITH LOCAL GOVERNMENT AND NGOS

Reefmap worked together with and received practical support from the Mayor's Office of Corn Islands. During the fieldwork period the Reefmap team had an intense dialogue with members of staff including: Roberto Ow (Mayor), Dr David Somarriba (Vice-mayor), Felix Archibold (Fisheries), Gustavo Zapata (Environment), Melvin Downs (Catastro / Land Planning), Cynthia Dixon (Used Oil Disposal) and Xiomara Zapata (Social Welfare). These meetings helped to ensure that project activities and outputs would be integrated with and support environmental work conducted by local authorities. The mayor's office provided the Reefmap team with office space as well as photocopying and printing facilities.

Reefmap collaborated with RAAN-Asdi-RAAS and the Movement for the Development and Defence of Corn Island (MDDCI). The RAAN-Asdi-RAAS program (funded by the Swedish International Development Co-operation Agency) works to support development in the Atlantic Autonomous Regions (RAAN and RAAS). RAAN-Asdi-RAAS provided financial and logistical support for the university involvement and the execution of a workshop and public meeting.

The MDDCI is a local social/environmental organization engaged in community affairs and environmental education and protection. One of their main campaigns focuses on the conservation of the island's swamps. The close collaboration that was initiated with the Reefmap project was therefore focused mainly around the water quality study, which was adapted in order to support the campaign. The MDDCI provided Reefmap with insight into the island community and in-kind support in terms of housing and office space. They helped Reefmap organize talks in primary and secondary schools and members of MDDCI participated in the water quality survey and were trained to use the field kit equipment.

7. LOCAL COMMUNITY INVOLVEMENT

7.1. INTRODUCING THE PROJECT TO THE COMMUNITY

The success of the project is highly dependent on relations to the local community. Environmental management and conservation concerns everyone and for the project to give long-lasting results it was important to involve and inform as many people as possible in the project. The social studies that were part of the project were entirely dependent on the good will of the entire population, and it was therefore important to make sure that no one felt alienated from the project. In order to avoid project association with potential local political conflicts, personal contacts with diverse groups within the community were therefore actively pursued.

Figure 3 - Ulrika holding a lecture on the marine environment in the Corn Island Baptist School.

During the first week in Corn Island, Reefmap was introduced to the local population through a radio program, where the project and its objectives were presented in both English and Spanish. Also, meetings were held with local community leaders and organisations, such as heads of the churches on the islands and fisheries cooperatives. In the process of developing the social surveys, members of the team worked in different parts of the islands and thereby got the opportunity of associating with a broad part of the population. These actions helped spread the word and created a widespread interest in the project, greatly facilitating the studies and promoting the importance of environmental issues within the community.

During the international environment week members of the Reefmap team held lectures in primary schools on the project and environmental problems associated to the different studies (Fig. 3).

8. DISSEMINATION AND DISCUSSION OF PRELIMINARY RESULTS

In order to promote environmental issues and to present the preliminary results of the project to the local population, a public meeting was arranged on the 25th of June. The meeting provided a great opportunity for the Reefmap team to discuss aspects of the project with a greater part of the community. This assisted in providing a deeper understanding of social issues related to environmental management on the islands, thus laying the base for ensuing projects.

Figure 4 Workshop at Great Corn Island discussing the preliminary results and future aspects of environmental management and community involvement.

With the aim of ensuring an integration of the Reefmap results into local organisations and institutions, a workshop was held on the 26th of June (Fig. 4). It was attended by representatives from local government, community groups, fisheries administration and university staff and students. The preliminary results of the project were presented and implications for future management strategies were discussed. Focus was directed on environmental problems on the islands and the role and needs of the participating parties in providing solutions for these problems. Some of the specific topics discussed were:

- The significance of, threats to, and future management of marine and coastal resources on the Corn Islands.
- The potential uses and users of environmental data and maps from the Reefmap project.
- Potential solutions to problems and the role of community in fisheries management.

The workshop played an important part in assessing the potentials and pitfalls for future initiatives on the islands. It laid the base for the production of project outputs that will benefit the local community and research, and enable a continuation of the project.

9. ACKNOWLEDGEMENTS

9.1. PROJECT PATRONS

Many thanks to Professor David Bellamy for acting as the President of the Reefmap project and for contributing kind words of support to aid publicity of our activities to Martha Holmes of the BBC (Blue Planet) and Mr Peter Raines of Coral Cay Conservation who acted as the projects patrons and as well known environmentalists also helped to promote the cause of the project and attract support and funding.

9.2. FINANCIAL SUPPORT:

The Reefmap Project team would like to acknowledge the generous contributions provided by the Natural Environment Research Council, The Royal Geographical Society with the Institute of British Geographers, The University of Newcastle Exploration Society, The Rufford Foundation, Swedmar/SIDA, PADI Project Aware, Coral Cay Conservation, The Gilchrist Educational Trust, Brooks

Bank Valves Ltd, RAAN-Asdi-RAAS, Dive Little Corn, Casa Iguana and private donations from Sir Bruce MacPhail, Mr. Peter Raines and Ms Savage.

9.3. ADVICE, LOGISTICAL AND INKIND SUPPORT

Thanks to Kristian Teleki (ICRAN), Major Peter Ormerod (Raleigh International), Dr Rob Nunny (Ambios), Dr Robert Foster Smith (Envision Mapping) and Joe Ryan (Carlbro International) for their initial encouragement for the idea of Reefmap and support with advice and contacts for funding and logistical support.

Dr Ed Green (WCMC) for the contribution of the Landsat Imagery and Dr Alisdair Edwards (Newcastle University) for help with the image preparation. Dr John Bythell, Dr Jeremy Hills, Dr Rob Upstill-Goddard and Dr Ivan Weir (Newcastle University), Dr Judith Lang and Dr Robert Ginsburg (AGRRA) for their advice and supervision concerning the structure and analysis of the project studies and particularly Dr Robert Foster-Smith and the staff at Envision Mapping for their encouragement and practical support both in the field with the RoxAnn AGDS surveys and back in the UK with the data analysis and contribution of office space.

In Central America, great thanks to Alvaro Segura (INRECOSMAR, Costa Rica) and Yamil Zapata for providing their scientific expertise. Joe Ryan (Carlbro International), Amanda Procter (Casa Canadiense, Managua), Janet and Marcos Gomez, Mariska Weierman (DIPAL), Ricky Jackson (Acopio Jackson), Grant and Cathy (Casa Iguana), Was and Elly (Dive Litte Corn), Jeff McCrary (UCA), Edmundo Roman, George Morgan (Pasenic) and the CBA (the Atlantic Biological Corridor) for logistical support and advice.

Norma Dixon Downs (Movmiento para la defense y dignidad de Corn Island) for her amazing vision, fighting spirit, trust and inspiration. Rene Cassells (BICU), Karen Joseph (URACCAN) and Doleen Miller (RAAN-Asdi-RAAS) for enabling the participation of students and staff from BICU and URACCAN.

Liza Gonzales (MARENA), Danilo Rosales (AdPesca), Sergio Martinez (AdPesca), Manuel Perez (AdPesca), Rodolfo Sanchez (AdPesca) and Renaldi Barnutti (AdPesca) for the lending their official support and advice to the project. The Corn Islands Mayor’s Office for participation and providing office facilities, especially Roberto Ow (Mayor), Dr David Somarriba (Vice-mayor), Felix Archibold, Gustavo Zapata, Melvin Downs, Cynthia Dixon and Xiomara Zapata.

And finally, to everyone who participated in the hard fieldwork for their interest, persistence, professionalism, friendship, and for sharing many laughs:

MUCHAS GRACIAS!

CHAPTER 1: FISHERIES STUDIES

CHAPTER 1, SECTION A: FISHERIES SOCIAL STUDY

Social structures and perceptions of artisanal fishers on the Corn Islands: Implications for co-management

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ABSTRACT

After recent declines in catches, co-management has been proposed as a potential management regime for the artisanal lobster fisheries of Corn Islands, Nicaragua. Co-management, where management responsibility is shared between authorities and resource-users, has recently been acknowledged as an efficient, cost-effective complement to traditional centralised management strategies. Previous studies have found social structure to be one of the main components determining the framework and success of potential co-management. In order to identify barriers and find potential structures for resource-user participation in management, this paper examines socio-cultural and functional groupings in the fisher community and whether these are linked with fishers' perceptions of resource decline, regulations and management responsibility. Qualitative background data was collected through unstructured interviews and in a workshop with key stakeholders. Quantitative data on social and functional background and perceptions of the fisheries was collected through structured interviews with fishers. Data was examined using Principal Components Analysis to display groupings in the fisher community, Discriminant analyses to find correlations between groupings and perceptions, and X2 analyses to validate the significance of these correlations. The fisheries perceptions' survey shows that both the existent and most of the proposed regulations generally have strong support within the fishing community. There is no consensus on what is causing decline in the fisheries, but a majority of the fishers feel that foreign-owned industrial boats are to blame, and diving is mentioned by half of the fishers as a reason. A majority feel that it is the responsibility of the national government to ensure the lobster stock recovery, while half of the fishers see themselves as responsible. The fisher community is grouped mainly by fishing technique and ethnicity, where the vast majority of those who fish by SCUBA diving are Mískitu. The community as a whole was found to be rather homogenous in its perceptions of the fishery and its management but for a few exceptions. Those who fish with traps are generally more positive to a proposed closed area (probably because they do not fish in the proposed area), are more inclined to see diving as one of the reasons for the decline of lobster catches, and would like a ban on diving. The general consensus regarding most management schemes shows a good potential for co-management, but the issue of diving and its linkage to conflicts between different ethnic groups in the community, could pose an obstacle to collaboration. A lack of organisation and leadership in the fisher community presents a barrier towards fisher participation in management, but successful management initiatives in Little Corn Island may provide a role-model. In order to instigate fisher confidence in prospective collaboration with authorities, the government may have to demonstrate more strongly their willingness to stricter regulation of the large-scale industrial fishery.

1. INTRODUCTION

The lobster fishery of the Atlantic coast is a major contributor to the economy of Nicaragua, providing an important source of employment and export incomes for the country (ca US$ 44 million or ca 7% of the total export incomes in 2002 [1, 4]). The fishery seems to have followed a path common to many other shellfisheries of Latin America [5]: starting off as a small-scale operation directed towards sustenance and a limited local market; followed by an opening up to export markets and a more or less un-limited exploitation; resulting in a decline in catches and CPUE (Catch Per Unit Effort) during the past few years (Figures 1 and 2); leading to the introduction of seasonal closures of the fishery [6]. The fisher community are increasingly concerned with this development, as they have few alternatives for livelihood [7]. In light of the recent development, and as problems with the fisheries regulation has gradually become more evident, fishers and local authorities have started to raise their voice for increased involvement in the management processes [7, 8].

In fisheries management science, user participation and co-management of fisheries has been put forward as a more viable alternative to traditional top-down, centralised, resource-focussed management strategies Participation of resource users in the decision-making is assumed to enhance compliance by making the management regime more legitimate. It is also likely to make users groups more knowledgeable of, and thereby committed to, the management regime [9]. Co-management can also promote community-based economic and social development, decentralisation of resource management decisions, further cooperation between resource users, create more responsible attitudes towards resource use, promote learning and reduce conflict through a process of participatory democracy [10, 11]. The objectives of co-management correspond with current campaigns, supported by foreign aid agencies such as the Inter-American Development Bank, SIDA and DANIDA (the Swedish and Danish development assistance agencies), for decentralisation of power and strengthening of local and regional government of the Autonomous Regions of the Atlantic coast of Nicaragua [12].

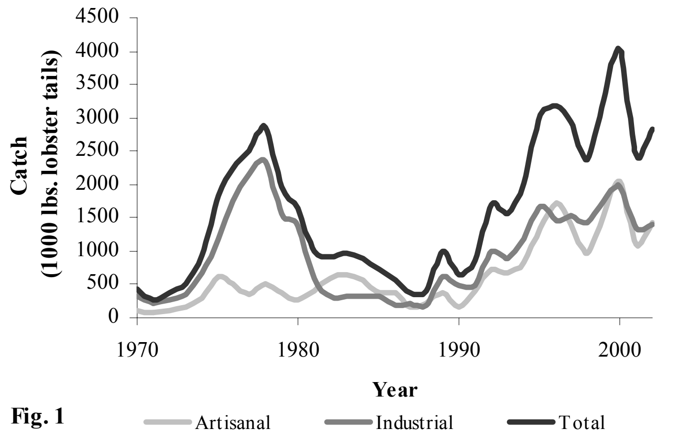

Fig. 1

Figure 1. Historical trends in catches of spiny lobster (*Panulirus argus*) on the Atlantic coast of Nicaragua [1]. Catches are shown in 1000 lbs. lobster tail, and displays catches from the artisanal and industrial sectors separately as well as the total catches. A notable decline in catches can be observed.

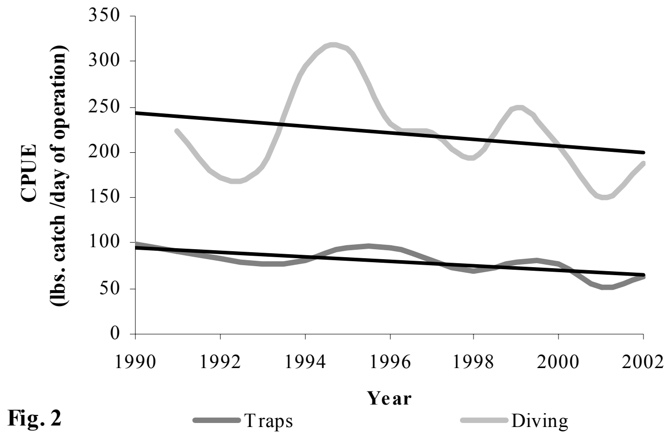

Fig. 2

Figure 2. Historical trends in Catch Per Unit Effort (CPUE) of the industrial lobster fishery on the Nicaraguan Atlantic coast [1]. The graph shows a declining trend from after the Sandinista period (1979 to 1989) up to 2002 of both industrial diving and trapping boats. CPUE is measured in lbs. of lobster tails caught per day of operation.

Corn Islands, being one the centres of the artisanal lobster fisheries of the Atlantic Coast of Nicaragua, has been suggested as suitable for a pilot project for co-management in the past [13]. Fishers here have called for increased and more effective regulation of the fisheries and have previously formed groups trying to co-ordinate efforts for increasing and improving regulation of the fisheries [7]. In line with this, a municipal fisheries officer has recently been appointed and a fishery commission consisting of representatives from national and local authorities, as well as industry has been set up [14]. However, exact role of the fishery officer and the fishery commission are still unclear and representation from the fishers in the council has not been properly defined.

The success of co-management regimes is highly dependent on designing social organisations and institutions where all stakeholders are justly represented [11]. If some groups feel alienated or poorly represented, they may boycott the decision-making process and thereby reduce effectiveness of or immobilise the management regime [15]. Fishers are seldom a homogeneous group and may be divided by functional factors such as gear type, or geographically by fishing grounds [9]. Fishers may also be grouped by socio-cultural variables such as ethnicity, religion or origin [15]. Fishers may have different perceptions of problems facing the resource and views on how the fisheries should be managed, depending on their role in the fisheries. Comprehension of this relationship is important, in order to promote understanding between different interest groups and thereby prevent conflict that may endanger the success of the management regime. This paper will examine the potential for and barriers to fisher involvement in management in Corn Island by:

- Investigating groupings in the fisher community by socio-cultural and functional factors.
- Surveying perceptions of fishers in the Corn Islands of Nicaragua towards: reasons for decline in the fisheries, current and potential regulations, and parties responsible for the recuperation of the lobster stock.
- Determining differences in perceptions between groupings in the fishing community.

2. METHODOLOGY

2.1. QUALITATIVE ASSESSMENT

In order to get a general overview and background to the main issues, problems and conflicts facing the fishing community of Corn Islands, semi-structured interviews were undertaken with key informants such as:

- Artisanal fishers
- Industrial fishers
- Owners of fisheries processing plants and "acopios" (middlemen)
- Fisheries cooperatives/ organisations
- Management planners: Representative from the Direction of Natural Resources at the Ministry of Finance)
- Regulation enforcers: Representatives from the coast guard and AdPesca (the central fisheries administration)
- Fisheries and marine researchers from CIPA (Centre of Fisheries Research; part of the governmental fisheries administration), BICU (Bluefields Indian Caribbean University) and URACCAN (University of the Autonomous Regions of the Atlantic Coast of Nicaragua)
- Representatives from local government and administration: the vice-mayor and the municipal fisheries officer.
- Representatives from local NGOs

In order to further investigate differences and similarities of attitudes towards regulation, to discuss future management options, and possible structures for future co-management, a workshop was held with representatives from: the civil society (NGOs, churches and fisheries organisations), the mayors' office of Corn Islands, local Universities (BICU and URACCAN), AdPesca and the coast guard. Information gathered from the qualitative assessment has been used to draw conclusions about the quantitative assessment (see 2.2 below).

2.2. QUANTITATIVE ASSESSMENT

To define groupings within the fisher community and to quantitatively assess perceptions of fisheries decline and attitudes towards management, 198 questionnaires with closed questions were collected. The questionnaire survey was carried out with the help of students from URACCAN and

1. Social and functional characteristics			
Name	Age	Residential area	Origin
Ethnicity	Schooling	Years in Corn Islands	Captain or Sailor
Industrial or Artisanal	Boat length		
2. Fishing type (Yes or No)			
Free diving lobster	Lobster traps	Lobster diving	Cast net for bait
Free diving fish	Fish traps	Hook and Line	Conch diving
Free diving conch			
3. Why are there so few lobsters? Tick applicable			
Immigration	Natural cause	Foreign boats	Diving
Traps destroying bottom	Not enough regulations	Regulations not enforced	Others
Too many fishermen	People don't understand	People don't care	
4. Do you agree with the following regulations? (Yes or No)			
2 month closed season	4 month closed season	Annual quota	Ban diving
Ban on Spawning lobster	Size limit	Bigger gaps in traps	Limit number of traps
Closed areas	2 nm area		
5. Who should make sure the lobster comes back? Tick applicable			
National Government	AdPesca	Coast guard	Mayor's Office
Fishermen	Companies	Others	

Table 1. Questionnaire describing functional and socio-cultural characteristics, as well as perceptions of fisheries resources and management directed towards fishers on Corn Islands, Nicaragua. Word explanations: *AdPesca* is the National Fisheries Administration, and the *Companies* are the middlemen (commonly known as "Acopios") and the processing plants.

BICU. In order to give a representation of fishers from all over the island, fishers were encountered by doing transect surveys through residential areas. Fishers were also interviewed at fish collecting centres (acopios) on different parts of the islands. The questionnaires were aimed mainly at artisanal fishers but some industrial fishers were included in order to enable assessment of potential differences between artisanal and industrial fisheries. The questions asked can be seen in Table 1.

2.3. DATA ANALYSIS

To establish what characteristics (Questions 1 and 2 in Table 1) defined different groupings of the fishermen, a multivariate statistical ordination technique, Principal Component Analysis (PCA), was carried out in Minitab statistical software). The PCA analysis is used to display the underlying data structure, and distributes the data along axes to show the maximum spread of variability in the data. The PCA analysis was used to display the spread of the characteristics within the population. Two types of plots were made:

- A variable plot showing the relation between the characteristics in the population, where characteristics placed far from the axes define groups which share characteristics with a high deviation from the general mean of the population.
- A sample plot showing the spread of the individuals within the population according to their characteristics, with displays of the sample plot demonstrating the spread of each of the characteristics.

Discriminant analyses were conducted on the data in SPSS (statistical software) in order to assess which social and functional groups indicated by the PCA, were correlated with differences in perceptions and attitudes towards fisheries and management. X^2 analyses with Bonferroni adjustments were used to test the significance of the differences in perceptions between different groups.

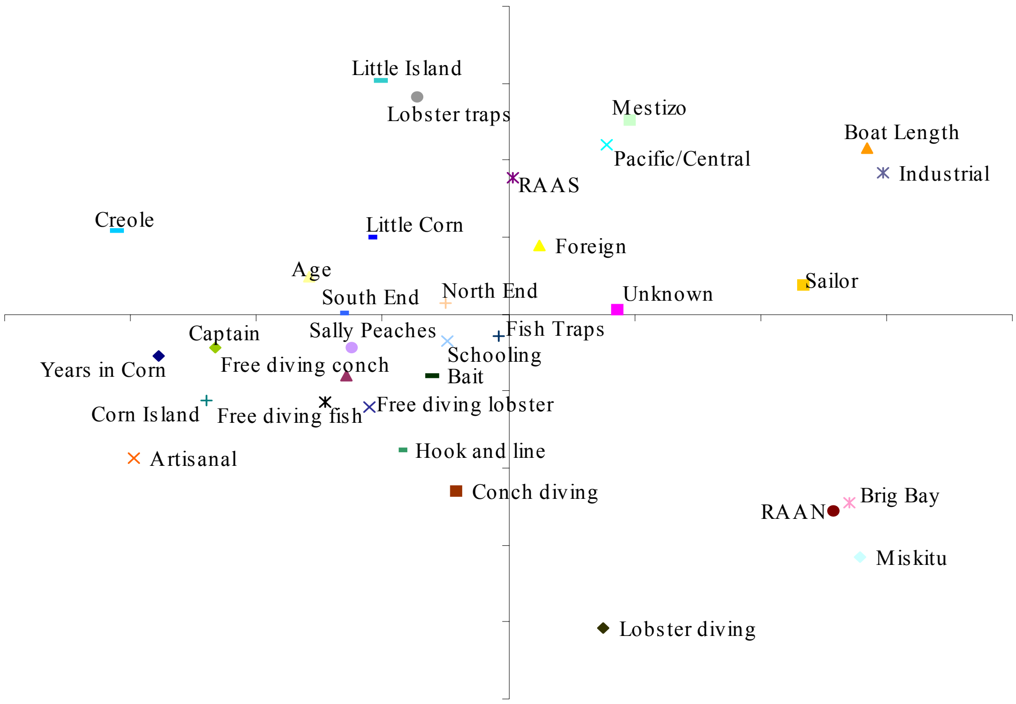

Figure 3. The variable plot resulting from a PCA analysis of socio-cultural and functional characteristics that define groupings in the fisher community of Corn Islands, Nicaragua. Variables far from the centre of the plot are unevenly spread in the population and define a separate group. For example, Miskitu fishermen are a distinct group that live in Brig Bay and are originally from the RAAN. Variables positioned close to each other occur in the same group of individuals. The variables shown are: Age; Schooling; Area of residence: *Brig Bay*, *Sally Peaches*, *North End*, *South End*, *Little Island*; Ethnicity: *Creole*, *Miskitu*, *Mestizo*; No. of Years in Corn Island; Origin: *Foreign*, *Pacific/Central*, *RAAS (Southern Atlantic Autonomous Region)*, *RAAN (Northern Atlantic Autonomous Region)*, *Corn Island*, *Little Corn Island*, *Unknown*; Artisanal or Industrial; Captain or Sailor; Boat length; Fishing type: *Lobster Traps*, *Fish Traps*, *Hook and Line*, *Bait*, *Lobster Diving*, *Conch Diving*, *Free Diving Conch*, *Free Diving Lobster*, *Free Diving Fish*.

3.1. FUNCTIONAL AND SOCIO-CULTURAL GROUPINGS IN THE FISHER COMMUNITY

The variable plot and the sample plots that resulted from the PCA, showing groupings of the functional and socio-cultural characteristics, can be seen in Figure 3 and 4. One of the main groupings was found to be artisanal vs. industrial fishers, mainly due to the differences in boat length, but more importantly none of the industrial fishers interviewed were originally from Corn Island. Many of the industrial fishers are recent immigrants, and to a greater extent Miskitu or Mestizo (This correlates with data collected from ship logs where most industrial sailors are Miskitu or Mestizo while most of the captains are Honduran). There were also more sailors in the industrial group (as crews are bigger on industrial boats, ca 12-13 people, than on artisanal boats, 2-4 people, the amount of industrial captains interviewed were naturally smaller).

The fishers were also grouped by ethnicity and fishing type, where fishers working solely with traps were mainly Creole while all divers were Miskitu. Most of the Miskitu are originally from the northern region (RAAN) while the Creole are either native to the islands or from the southern region (RAAS). A big part of the Creole population is mainly concentrated on the northern part of Great Corn Island (North End and South End) while the Miskitu population and most of the recent immigrants live in the more urbanised, densely populated area of Brig Bay. Little Corn Island is generally more homogenous compared with Great Corn Island, with no divers or industrial fishers, and nearly exclusively Creoles. There are virtually no Miskitu on the Little Island, and recent immigrants are Mestizo and Creole from RAAS, the central parts or the pacific side of Nicaragua, or foreigners. Age and Schooling were found to be homogeneously distributed within the fisher community.

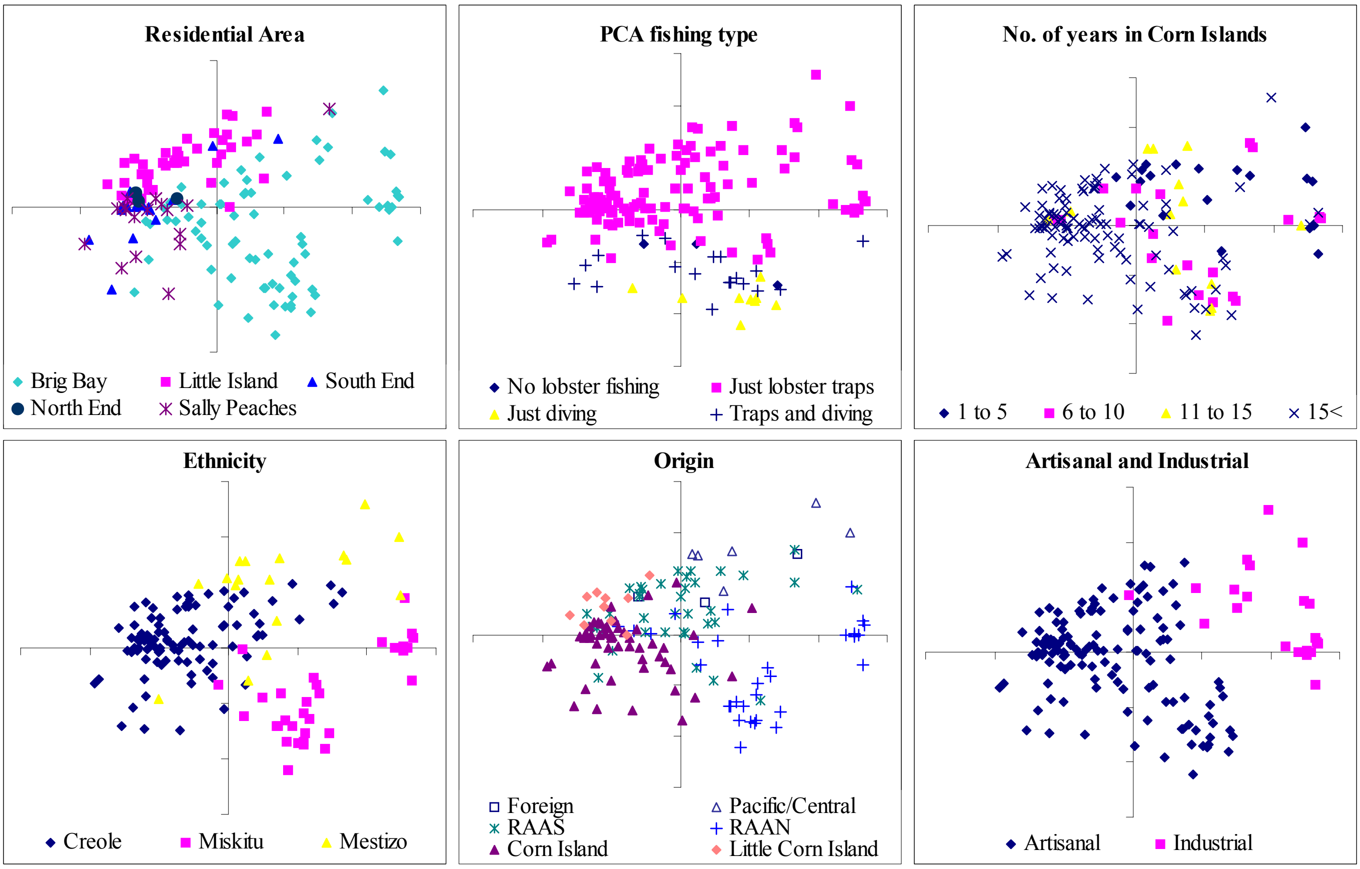

Figure 4. Sample plots resulting from the PCA (Principle Component Analysis), showing the spread of individuals within the fisher community of Corn Islands according to their functional and socio-cultural characteristics. All graphs show the same plot, but display different characteristics. Plots with characteristics that do not show any tendencies to separate clusters of data, i.e. defined groups, have been left out (*Captain or Sailor*, *Schooling* and *Age*). However, *Years in Corn Islands* is shown as to demonstrate an example of a less grouped characteristic.

3.2. SURVEY OF FISHERS' PERCEPTIONS TOWARDS THE RESOURCE & MANAGEMENT

3.2.1. REGULATIONS

The results of the survey of attitudes towards regulations show that the existing regulations (size limit; not catching spawning lobster; closed season of two months [16]) have strong support within the fishing community (94; 88; 97 % agreement respectively). Having bigger gaps in the traps to let out small lobster, and an increased 4 month closed season, which are a regulations that will be introduced for the coming season 2003-2004 [6], also has relatively strong support (83%; 70% agreement). The general attitude towards prospective regulations (closed areas, limits to amount of traps and ban diving) was also positive (averaging 73% agreement). The closed area surrounding the islands to a distance of 2 nm, that had previously been attempted the municipal government still had a rather strong support (76% agreement), while the proposition of having individual quotas on catches was not as popular (44% agreement).

3.2.2. REASONS FOR DECLINE

There is no main consensus of exactly what is causing the decline in the fisheries even though a majority of the fishers (67%) feel that foreign-owned industrial boats are to blame. Diving is also mentioned by half (49%) of the fishers as a reason for decline. Other factors that have been mentioned are: too many fishermen (27%), regulations not enforced (23%), not enough regulations (15%), traps destroying bottom (14%), illegal catches and trade of small or spawning lobster (14%), that people don't know better (6%), stealing of traps (3%), immigration (3%) and that people don't care (2%). Very few people (2%) are the opinion that the decline is because of natural causes. Individuals have also mentioned problems such as: no biologist on board industrial boats as inspectors, improvements in techniques such as the introduction of GPS and pollution.

3.2.3. PARTIES RESPONSIBLE FOR THE RECUPERATION OF THE LOBSTER STOCK

A majority (73%) of the fishers feel that it is mainly the national government that bears responsibility for making sure that the lobster stock recovers. Half (50%) of the fishermen feel that the fishers themselves are responsible. Other responsible parties mentioned are: the mayor's office (23%), the fisheries plants and collecting centres (12%), the coast guard (9%), the community of Corn Islands (4%) and God (4%).

3.3. CORRELATIONS BETWEEN FACTORS DEFINING GROUPINGS AND PERCEPTIONS

3.3.1. FISHING TYPES

According to the discriminant analysis where fishers were grouped by fishing type (just traps, just diving and those who fish both with traps and by diving) the main variables that separated the groups were:

- Reasons for decline: that people don't care, regulations not enforced and diving
- Responsible parties: fishers, companies and coast guard
- Regulations: 2nm closed area and closed area

One-way X^2 analyses, with Bonferroni adjustments of significance level, showed the following perceptions to be significantly different between fishing type groups:

- Trappers are more positive towards a 2 nm closed area (just traps vs. just diving, $p = 0.005$; just traps vs. traps and diving, $p = 0.004$)
- Trappers are also more positive towards closed areas in general (just traps vs. just diving, $p = 0.001$; just traps vs. traps and diving, $p = 0.008$)
- Trappers are generally more inclined to see diving as a reason for the decline of lobster than fishers dedicated to trapping and diving (just traps vs. traps and diving, $p = 0.002$).

3.3.2. ETHNICITY

According to the discriminant analysis, the main variables that separated the ethnic groups were:

- Reasons for decline: not enough regulations, diving, limit to no of traps, traps destroying bottom and others
- Responsible parties: mayor's office, coast guard and don't know
- Regulations: ban diving and 2 nm closed area

A X^2 analysis, with Bonferroni adjustments of significance level, showed the following perceptions to be significantly different between ethnic groups:

- Miskitu were less positive to banning diving than Creole ($p = 0.001$).
- Creoles are more prone to mention diving as a reason for decline than Miskitu ($p = 0.002$)

4. DISCUSSION

4.1. IMMIGRATION AND ETHNIC GROUPS IN CORN ISLANDS

The results of the quantitative analysis of groupings in the fisher community of Corn Islands should be seen in the context of the demographic history of the islands. In the last decades, the islands have experienced a major increase in population from 2,483 to 8,200, due to immigration [17]. The main reason for the increase in population has been the expansion of the fisheries [17].

This has lead to a change from a rather homogeneous Creole-dominated community to a more diverse population with 30% Mestizo, 40% Miskitu, and 30% Creole [17]. The introduction of new ethnic groups with different languages, history cultural traditions has lead to a more segregated community [17, 18]. Ethnic groups are divided by residential area, economic and political status. On Great Corn the northern part of the island (North End, South End and Sally Peaches) is clearly dominated by a native Creole community living almost entirely dependant on artisanal fisheries [17]. Many people on this part of the island express a strong sense of cultural pride, and do not always look kindly on the introduction of new ethnic groups on the islands.

The Mestizo and Miskitu population generally have a lower level of income and live in the more densely populated areas of Brig Bay [17]. While many Mestizo are dedicated to commerce, the Miskitu work mainly within the fishing industry or as artisanal fishers [17]. Mestizo or Creole [17] occupy most positions of economic or political status in the community and representatives of the Miskitu community describe themselves as politically marginalized and show a general distrust towards the political establishment. Complexities in land ownership leading to conflicts [19], and plans from the municipal government of restricting immigration [17] has caused further polarisation of ethnic groups.

4.2. DIVING: ON THE VERGE OF EXTINCTION?

The PCA analysis shows that the divers as a group are socio-culturally rather distinct group, consisting mainly of Miskitu immigrated from RAAN all living in the area of Brig Bay. According to information collected from key informants this is a rather recent development. Apparently there used to be more divers that were working for different acopios all over the island. However, this changed in 2000 when the acopio owners jointly decided to stop buying lobster from divers in order to encourage a phase-out of the artisanal lobster diving in Corn Islands. Some of the divers converted to traps while most of them were assembled in acopio South West Bay in Brig Bay. The Association of Miskitu Artisanal Fishers, APAM, was formed as a cooperative to run the acopio. The assembling of all divers in one place is likely to have further polarised the fishing community, but also created a stronger voice for the Miskitu community.

The decision to stop working with divers was based on concerns for the safety (diving accidents due to lobster fishing are frequent on the Nicaraguan Atlantic coast [20]) and that diving was contributing to the decline of the fishery. Another reason that is likely to have contributed to the decision is that many of the trap fishers accuse the divers of going down next to the buoys that mark the traps, to steal lobster and destroy traps [21]. This led to a resolution from the Municipal council not allow any increase in the number of divers as of May 2002 [22] and to work for a phase-out of diving.

While this decision is supported by a big part of the fishery industry and community there are still some people (such as the owner of one of the two processing plants on the island) that question the validity of the decision to phase-out diving based on ecological arguments. And it may be a valid question as there has not yet been any evidence to show that diving would be more destructive to the lobster stock than trapping (there are different theories ranging from divers being able to reach the last residual stock to divers scaring lobsters away by spreading lobster blood in the water). In fact, many fishers are worried about the effects that traps have on lobster habitats (see Section 3.2.2.).

With this background, it is not surprising that the results of the discriminant and X^2 analyses show that trappers are more prone to see diving as a reason for decline, and that Creoles are more positive to a ban on diving than Miskitu. This may seem like an obvious conflict between the groups that could threaten to hinder attempts of co-management, but there may be space for compromise. It should be noted that nearly half of the divers are not opposed to a suggested ban on diving, and that leaders of APAM are positive to the ban on the condition that the divers are given financial support to convert to trapping.

4.3. CLOSED AREAS

A closed area 2 nm surrounding the islands was proposed by the municipal government in 2002, reserving it for eco-tourism purposes and as a lobster spawning and nursery area. The municipal government tried to enforce this but after protests from divers to the central government it was found that this kind of legislation was beyond the jurisdiction of the municipal government. The reason to why divers are more inclined to dislike this decision is that they often fish in shallower waters than trap fishers.

4.4. "FOREIGN BOATS" AS A REASON FOR DECLINE

The main worry of the fishers regarding the decline of the stock is the "foreign boats". The foreign boats refer to the *extensive* illegal catches that are taken in Nicaraguan waters by boats of other nationalities, a problem that is also recognised by the government as one of the main problems of the fisheries [23, 24]. It also refers to the so called "nationalised" industrialised boats (Honduran boats under Nicaraguan flag). The attitude towards "foreign boats" is also an illustration of how many artisanal fishers see industrial boats as a threat. Even though there is an area of 25 nm around the islands that is reserved for artisanal fishers [25], many fishers report that there is no compliance with this (this has also been confirmed by captains on industrial boats). Many fishers also worry that there are too many industrial boats with too big an effort. The official limit of 1600 traps per industrial boat is clearly not being followed [26], when most industrial boats have 3000 to 6000 traps (according to interviews with industrial captains).

4.5. FISHERS AS PART OF MANAGEMENT?

The main problem with the proposed fisheries commission as it stands proposed by the Municipal Council is that the only representation for the fishers is the head of the Fisherman's Union, an organisation with ca 45 members out of the estimated 600 artisanal fishers in the Corn Islands. It is estimated that only 25% of the fishers on Corn Islands are organised [17]. The only other organisation that does exist is APAM, which has ca 100 members. The lack of organisation is a general characteristic for the islands as a whole, which is dominated by a highly individualistic culture [17]. However, the great amount of fishers that see themselves as responsible for the recuperation of the lobster stock (see Section 3.2.3.) show a willingness to take on a bigger part of the duty of protecting and sustaining the resource. Many fishers have also expressed a strong desire to be part of a fisher organisation and to participate in management decisions. The main reasons for not being organised mentioned, are the lack of leaders that can be trusted, and good organisation structure. Some fishers also base this with previous experiences with corrupt organisations. The fishers' general agreement of the regulations set up by government also show a good potential for a smooth cooperation between user groups and authorities in a co-management arrangement.

4.6. LITTLE ISLAND AS A ROLE MODEL?

As opposed to Great Corn, Little Corn, which has a smaller population, has not been put under the same pressure from immigration. Even though it has had an increase from ca 400 to 1,100 since 1971 [17], most of the immigrants are from similar background (Creoles from Great Corn or the

RAAS). Neither has diving been introduced to the island. The small and homogenous community has lead to a stronger organisation of the fishers centred around the two acopios on the island, who call to meetings whenever issues relating to the fisheries need to be discussed. This informal but yet existing organisation has enabled the islanders to enforce their own regulations of a ban on diving and a 2 nm no-fishing zone around the Little Island.

5. CONCLUSION

One of the most important barriers towards user participation in a co-management regime in Corn Island is conflicts between different ethnic groups and between divers and trappers. This conflict is rooted mainly in land owning issues and problems with theft and destruction of traps (overlapping fishing grounds). The other big problem is the lack of organisation of a majority of the fishers. A comparison with Little Corn Island can be shown as an example of the importance of socio-cultural homogeneity [27] [15, 28] and local leadership [29].

A phase-out of the diving can be seen as a potential solution to the conflicts between trappers and divers, on the condition that it is done in agreement with the divers and with a conversion to trapping. Another option could be to divide the functional groups into different fishing areas. However, due to the migratory behaviour of the lobster population and the current negative attitude of divers towards closed areas, this option may create further conflict with the distribution of property rights.

The main priority for enabling user participation in management is to find organisational structures for the fishers. Civil society and municipal government will have to work actively to support the existing as well as the formation of new organisations. The structures for management should strive to integrate ethnic groups and it may therefore be inappropriate to base structures on residence. Due to previous experiences of corrupt organisations a strong formalisation of structures will be required. In order to instigate fisher confidence in government, the control of the industrial fisheries should be improved.

6. ACKNOWLEDGEMENTS

The author wishes to thank Dr. Jeremy Hills for his patience, listening skills and guidance; Dr. Per Olsson for comments, inspiration and advice; Dr. Michael Tedengren for support and enthusiasm; Swedmar and SIDA (Swedish International Development Cooperation Agency) for funding the fieldwork period through the Minor Field Study Grant. This study would not have been possible without the persistent work and dedication of Yessenia Bello of BICU (thanks to Rene Cassells of BICU for enabling her participation) as well as Karen Joseph and her class in Fisheries Engineering at URACCAN. Thanks to Mauricio Lacayo and Doleen Miller of RAAN-Asdi-RAAS for enabling the workshop and the Nicaraguan students' participation in the project. The support from MARENA, AdPesca and the Corn Islands Mayor's Office has been invaluable, and I would especially like to thank Liza Gonzales, Danilo Rosales, Sergio Martinez, Rodolfo Sanchez, Manuel Perez, Renaldi Barnutti, Roberto Ow, Dr. David Somarriba and Felix Archibold. Thank you to Joe Ryan for background information and initial support, and to Janet and Marcos Gomez for making "su casa, mi casa". To Norma Dixon, of the Movement for the Defence and Dignity of Corn Islands, for her hope, determination and commitment in working to create a better world around her. Finally I would like to thank the fishers Corn Islands for giving me their time and for speaking their mind.

CHAPTER 1, SECTION B: FISHERIES SPATIAL STUDY

A spatial and economic analysis of the artisanal fisheries of the Corn Islands

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ABSTRACT

The spatial distribution of fishing effort is acknowledged as an important consideration for fisheries management. This paper uses stakeholder interviews to describe the spatial distribution of artisanal lobster fishing effort around the Corn Islands. The costs and benefits of using more distant grounds are examined by analysis of daily records of fuel expenditure and catches by divers and by stated typical catch rates at individual trap-fishing grounds. Artisanal fisheries extend over 50 km offshore to the north. Lobster fishing is more intensive north and west of the islands. At the scale of a 5 x 5 minute lat/long grid, trap fishing effort was highly aggregated (dispersion coefficient = 3.5). Diving had a regular dispersion (d.c. = 0.1), although this may have been due to the scale at which it was examined. Daily lobster catches by individual divers increased significantly with fuel expenditure ($p<0.05$) at a rate that would more than compensate for increased fuel expenditure while maximum catches stated by trap fishers also showed a positive relationship with distance from the islands ($p = 0.002$). Fishers may not perceive these positive trends in catch rate with distance due to considerable variability in catches. They may also take account of other costs of travelling further, which constrain the size of their resource space.

1. INTRODUCTION

Although most fisheries management science has focused on the quantification of characteristics aggregated over whole fisheries, the importance of understanding spatial variations has been argued by a number of authors [30-33] and there has been a resurgence in interest in spatially explicit management measures including Marine Protected Areas (MPAs) [34, 35]. Despite this interest, few studies have documented and analysed the spatial behaviour of tropical artisanal fishers who normally demonstrate highly aggregated distributions [36].

These distributions are the result of individual fishers' behaviour which is in turn affected by habits, perceived profitability and spatial patterns of the resources being targeted. Thus in order to understand these patterns and predict the effect of proposed management strategies one must understand the social, microeconomic and natural environment in which fishers make these decisions.

In this study a combination of mapping, economic analysis and semi-structured interviews are used to gain a spatial understanding of how artisanal fishers of the Corn Islands perceive and utilise the areas of the sea around them.

The objectives of this paper are:

- To describe spatial patterns of the usage of the sea around Corn Island by various sectors of the artisanal fishing fleet and highlight factors determining these patterns
- To investigate the costs and benefits of fishing farther from the island
- To place this in a microeconomic context and examine how spatial changes have interacted with other trends to affect the welfare of fishers.

2. STUDY AREA

The Corn Islands lie in the Nicaraguan sector of Caribbean Sea on the most extensive portion of the Central American continental shelf. Thus, there is no natural limit to fishing grounds imposed by bathymetry. The two islands are separated by about 15 km (Figure 1), Great Corn Island has the highest population density on the Atlantic coast of Nicaragua with a population of 7,100 residing in 10.3 km^2 while Lesser Corn Island, at about 5 km^2 is much less densely populated by about 1,100 people [37].

A profitable export fishery for the lobster, *Panilurus argus* has operated on the islands since the 1970s and has been the mainstay of the local economy since the 1980s [37]. SCUBA diving for lobster has gradually been replaced by trap fishing due to safety and environmental concerns. Diving is now predominantly practised by the Miskito ethnic group while most Creole fishers (and all fishers on Little Corn Island) use traps. Finfish (primarily yellowtail, *Ocyurus chrysurus*, other Lutjanids and Serranids) are also fished commercially using hand-lines although the relatively low price has led to considerably more emphasis being placed on the more valuable lobster stocks. Commercial artisanal fishers generally operate from fibreglass or wooden skiffs (*pangas*) 7-10 m long, powered by 40-75hp outboard engines, and crewed by 3-4 fishers. Fishers sell catches to one of 13 middlemen (*acopios*) who pass on the catch to one of the two Corn Island based companies for processing and export. The acopios also provide fishers with fuel, dive cylinders and credit on traps, boats and engines.

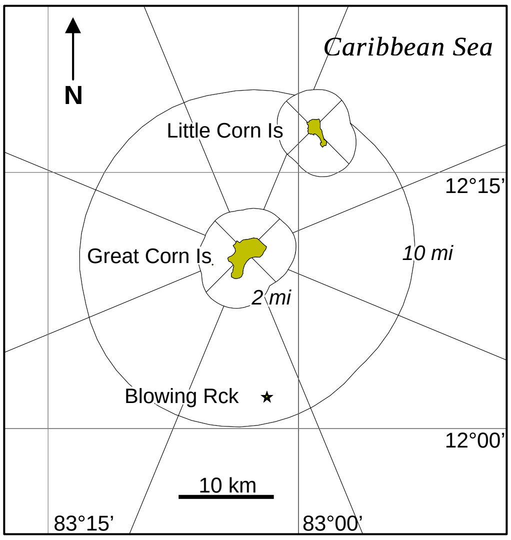

Figure 1. The Corn Islands, showing the 24 zones used to gain a rapid impression of fishing areas.

Government figures show that Lobster catches across the Nicaraguan shelf have declined in recent years [38]. In response, a closed season (*veda*) on fishing lobster has been imposed during May and June since 2002 in an attempt to provide some respite for the stocks. Local government and fishers are proposing that it be extended to four months next year. The municipality also passed legislation excluding commercial fishing from within two nautical miles of the island but this has not been enforced and divers still use the area (Corn Island Municipality, [38]).

Although only one lobster species is targeted, fishers clearly identify at least two different kinds of lobster through physical and behavioural characteristics. The stock is broadly divided into "red" and "white" lobster. In addition to colour differences, red or "stationary" lobsters tend on average to be heavier, are more likely to have eggs and are found in moderate numbers around the Corn Islands throughout the year in rocky habitat. White or "running" lobsters can be caught in large numbers on seagrass or gravel substrates in November to January as they pass through the area from the North (pers. comm., various Corn Island fishers).

3. METHODS

3.1. DATA COLLECTION

Two types of interviews were used to collect information on fishing techniques, costs and fishing grounds. A house-to-house, rapid survey gathered basic information including personal information, species targeted, gears used and boat characteristics. Interviewees were also asked to identify which of 24 broad sea areas they used for each activity (Figure 1).

Captains of boats were opportunistically sampled by meeting them at landing sites and socialising areas as well as following up recommendations by other fishers with visits to individual homes. An in-depth interview was conducted covering equipment used, their approach to selecting fishing grounds, typical catches and more precise locations of fishing effort. A flexible approach to mapping fishing grounds was required due to differences in navigational equipment, willingness to cooperate and understanding of maps. When possible, the position of each ground was determined by positions from a GPS (Geographical Positioning System) receiver recorded to the nearest minute of latitude and longitude. In other cases the approximate distance and compass direction of each ground was recorded. A few captains did not provide reliable position information, only stating the approximate direction and time to reach grounds or the names of grounds and their information was excluded from the spatial analysis. Interviewees also provided some or all of the following information about each ground: approximate size and shape, local names, typical good, poor and average catch rates, time and fuel to reach, frequency and intensity of use, substrate types and depths. In the case of lobster fishers, the proportion of "white lobster" caught at each ground was also recorded.

Information on costs of equipment, maintenance, licences, bait, fuel, tank hire (for divers) and payment to sailors was obtained from some cooperative fishers. Depending on the length of time fishers had been operating, they were asked about their memories of normal, maximum and minimum distances travelled to conduct fishing now, 10 years ago, during the 1980s and during the 1970s. Daily records of catches landed and fuel used by individual fishers during 2002 were obtained from one acopio and records of historic fuel, lobster and fish prices were obtained from the records of one of the fishing companies.

3.2. MAPPING FISHING LOCATIONS

Fishing areas from the house-to-house rapid survey were filtered to remove non-specific responses (e.g. "everywhere" or "all around"). The proportion of each type of fisher from each island using each zone was calculated and plotted using *MapInfo* GIS software. Responses were not weighted by area as the zones beyond 10 miles were of an indefinite area limited only by the maximum distance fished by each individual.

GPS positions were plotted directly into *MapInfo* while distances and directions obtained during interviews were used to estimate the position of other grounds in relation to a base map of the islands. Grounds on the opposite side of the island from a fishers home beach could be plotted in 5 ways: (1) "as the crow flies" distance and direction from the fisher's home port, (2) distance and direction from the nearest point of the island, (3) distance and direction from the first point on travelling around the island where a clear line of sight to the ground was available, (4) as 3 but including the distance travelled from home to get to the point where a clear line of sight was available and (5) measuring from the closest point on the island to but subtracting the distance travelled by the fisher from home to arrive at that point. Fishers who used GPS were assumed to cite distances and directions directly from their home port as they would be able to read this from the GPS display. Fishers who used transits (alignment of features on land) or compass bearings to reach grounds were assumed to state distance and direction from the point on the island when the first clear line of sight to the ground was available.

Interviews indicated that trap grounds extended for about 1 mile radius around each position so a 1 mile buffer was drawn around each trap location mapped and associated with the number of traps deployed. Distribution of effort across diving grounds was determined by giving each an "attendance coefficient" calculated as the inverse of the number of grounds mapped by each diver and assuming that an equal proportion of time was spent at each. The sum of traps deployed and attendance coefficients were aggregated over a 5 x 5 minute lat/long grid and the coefficient of dispersion (variance/mean) [39] between those grid squares which included fishing was calculated to categorise the type of distribution.

3.3. TRENDS OF CATCHES WITH DISTANCE TRAVELLED

Acopio records were filtered to select cases which included catches as well as costs for fuel and diving cylinders (to ensure the records corresponded to diving). Records of three lobster divers on 291 individual fishing days between July and December 2002 were selected. Square-root transformed expenditure on fuel was used as a proxy for distance travelled and was regressed against square-root transformed daily catches of lobster. Changes in fuel price were not accounted for as they only fluctuated by 12% during this period (Central American Fisheries, Unpublished data). One to five days were removed from the data on each fisher due to large residuals that had a strong influence on the regression. Removal of these points had no effect on the significance of the regression and gave coefficients more indicative of typical conditions.

For lobster trap fisheries, twenty fishers gave estimates of good, poor and/or normal catches per trip at each of 57 grounds. These were converted to CPUE according to the number of traps used at each ground and $\log_{10}$ transformed. Pythagoras' theorem was used to calculate the distance of each ground from the centre of the fisher's respective home island and Great Corn Island from Universal Transverse Mercator (UTM) coordinates. The transformed catch rates were regressed against square-route transformed distances to test whether more product was caught further from the islands.

3.4. CHANGES IN TIME

The normal, maximum and minimum distances travelled according to captains were analysed as 3 separate variables. Two-way ANOVA without replication was used to test each variable in turn for changes in time, with interviewee as a random factor and time-period ("Now", "10 years ago", "the 80s" and "the 70s") as a fixed treatment effect [40]. This analysis was repeated excluding any observations detected with high residuals (1-3 observations) to check that they did not change the inference of the test. Pairs of time-periods of particular interest were tested by paired t-tests with a Bonferroni correction to account for the six tests possible between 4 time-periods. A conservative probability of 0.0083 (i.e. 5% divided by 6) was therefore used to test the significance of results [41].

3.5. MICROECONOMICS OF FISHERS

Expenses and prices detailed from interviews with fishers and acopios were used to compile a simple microeconomic model of a representative trap fisher and lobster diver. In the real fishery capital costs are complicated by highly variable credit arrangements with acopios and exchange rates. To simplify capital costs they were calculated as depreciation plus mean interest as follows:

$$C = (V / l) + \frac{1}{2} V \times i$$

Where C is the capital cost of an item, V is the new price, l is the useful lifetime and i is the interest rate (5% was used[1]). These models were used to calculate the percentage of costs attributable to fuel for each fishery and the net income gained per pound of catch.

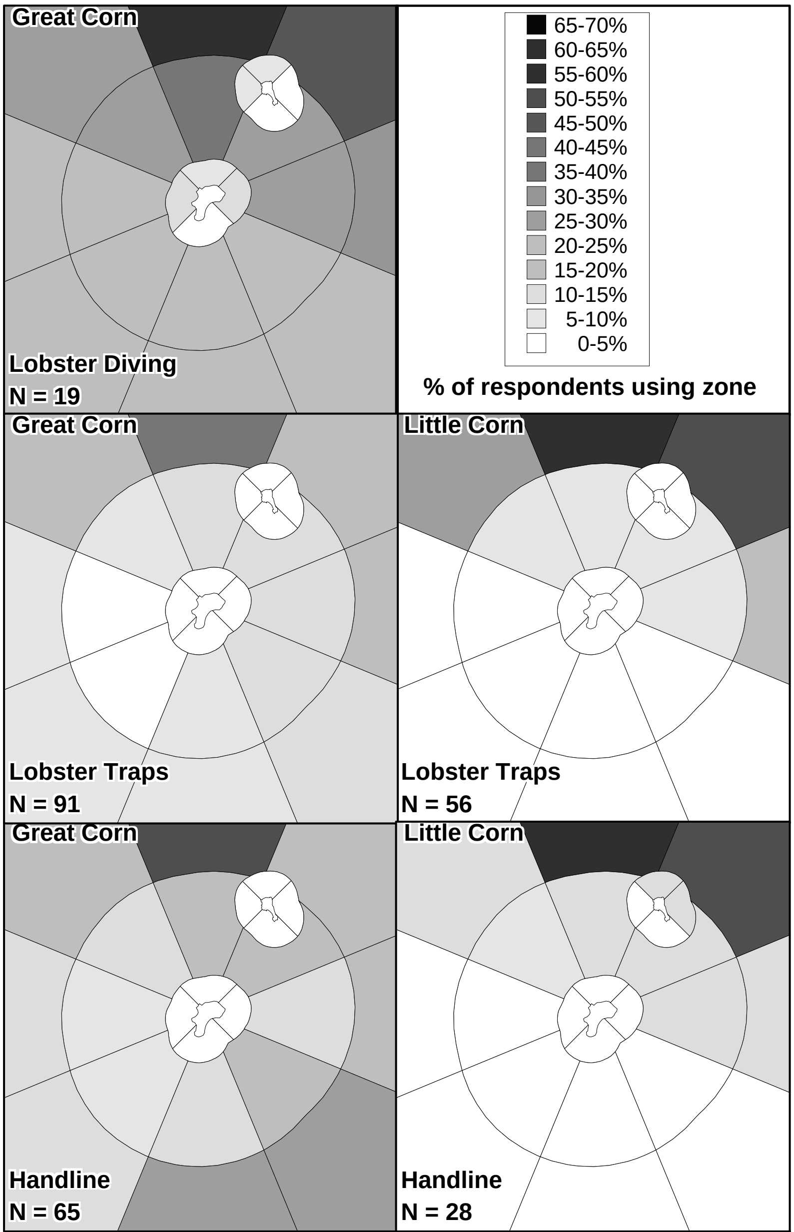

Figure 2. Percentage use of broad zones around the Corn Islands by different types of fishers from the two Islands.

4. RESULTS

231 Interviews were conducted with artisanal fishers, including different ethnic groups and fishing sectors from both Corn Islands (Table 1).

	Total	Island		Ethnic group			Main fishing gear		
		Great Corn	Little Corn	Miskito	Creole & Garifuna	Mestizo	Traps	Diving	Handline
Approx No fishers[1]	1700	1290	430	306	1230	151	560	80	460

[1] Some acopios do not overtly charge interest but lend in US dollars and pay for lobsters in Nicaraguan cordobas. From the fishers perspective this leads to an effective interest rate as the Cordoba has declined at a rate of 0.767 C$ per year over since January 2002 (www.xe.com/ict), which is roughly equivalent to 5%.

Household interviews	198	139	59	43	129	22	152	38	5
In depth interviews	33	24	16	7	26	0	25	7	1
Fishing site locations	196	158	38	91	104	1	60	115	21
Information on costs	16	8	8	4	12	0	11	3	0

[1] Calculated by multiplying government figures from ADPESCA (2002) up to total fishing population estimate of 1700

Table 1: Distribution of sample of fishers by home island, ethnic group and main fishing gear.

4.1. SPATIAL DISTRIBUTION OF RESOURCES UTILISED

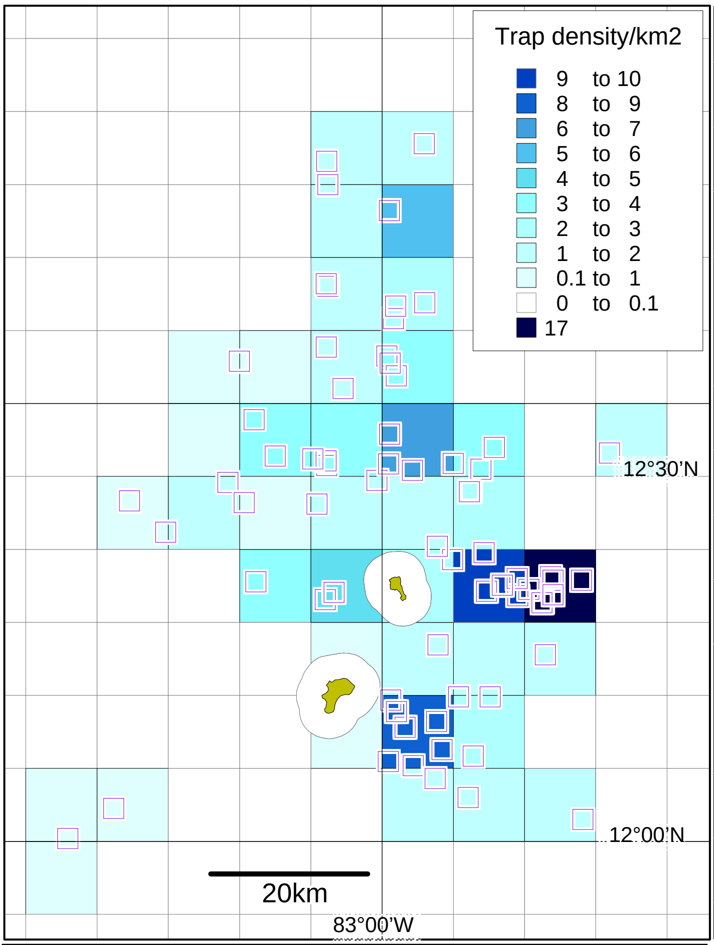

Figure 3. Estimate of trap density per 5x5 minute grid as a result of fishing by 12 Little Corn Island and 14 Great Corn island trap fishers.

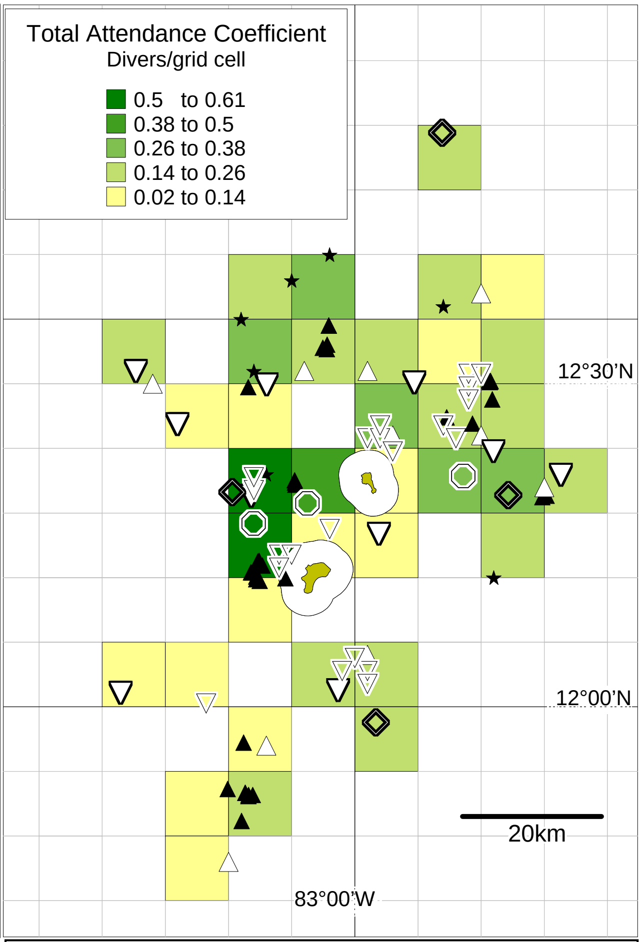

Figure 4. Lobster diver effort intensity by 7 Great Corn Island divers. Attendance coefficients assume divers spread effort evenly between grounds. Different points styles indicate 7 different divers.

Figure 2 illustrates the percentage of fishers from each island using each zone for different fishing techniques as indicated by the household survey. The northern zone beyond 10 miles of the island was used by the highest proportion of all types of fishers from both islands. No little Corn Island fishers interviewed used grounds south or west of Corn Island. Divers and hand-line fishers from Great Corn Island used a wider range of areas than trap fishers with more usage of southern zones. Few commercial fishers used the zone within 2 miles of the islands. Only 5-15% of divers and 10-15% percent of Little Corn handline fishers claimed to use any of these nearshore zones.

Few fishers used the zones within 10 miles west and south-west of Great Corn Island. Trap densities predicted from 29 in-depth interviews reinforce the importance of northern and eastern grounds for trap fishers indicated by the household survey and allow patterns to be seen at a higher resolution (Figure 3). Trap grounds extended farthest to the north (50 km from Little Corn Island) but the highest concentration of effort is seen 10-20 km east of Little Corn Island. The dispersion coefficient of trap density between 5 minute grid squares was 3.47 indicating a highly aggregated distribution of effort. Diving grounds are plotted from interviews with 7 divers with attendance coefficients summed by 5 minute grid squares (Figure 4). They show individual fishers ranging over a wide area in contrast to trap fishers who fished only 1-4 different grounds each. The dispersion coefficient of total attendance coefficient was 0.10, considerably less than 1 and indicating a regular distribution.

Interviews showed a clear distinction between the types of lobsters caught by area. Red lobster was reported to dominate catches in the east and south of the islands while grounds north and east were dominated by catches of white lobster (Figure 5).

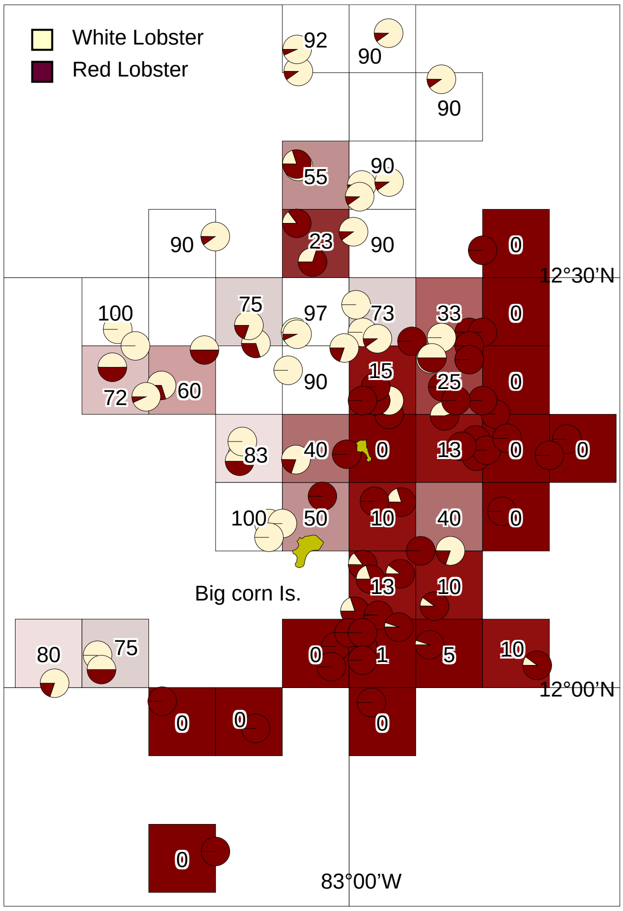

Figure 5. Relative distribution of red and white lobsters on the lobster fishing grounds around the Corn Islands. Pies show the proportions of red or white lobsters as estimated by fishers at individual grounds. Shaded boxes and numbers indicate mean

4.2. FACTORS AFFECTING SPATIAL EFFORT DISTRIBUTION

Factors affecting spatial effort distribution and fishing strategies varied between sectors. Trap fishers tended to keep to their individual grounds but move their strings of 2-10 pots between 10m and ½ mile at each setting in response to patterns of catches. Divers and hand-line fishers appeared to have a knowledge of many locations and would try them in turn guided by previous experience.

Some divers claimed to rotate grounds to allow stocks to recover and/or to avoid repeated deep diving. At the end of the veda and during strong northerly winds, divers target concentrations of lobster close to the islands. After two or three days, catches decline due to harvesting and the lobsters moving back into to deep water. One diver estimated that he would fish in this area for 2-3 days at a time 6-7 times per year.

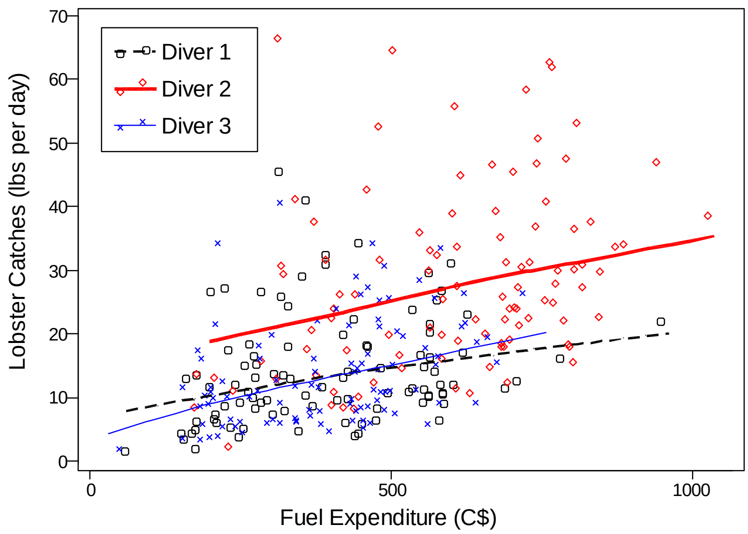

Figure 6. Actual catches and fitted regressions of daily lobster catch against expenditure on fuel by 3 Corn Island divers between July and December 2002.

Navigational techniques varied between fishers and included the use of landmarks and prevailing sea direction, compasses and GPS. Seventeen out of 28 fishers had acquired GPS within the last 11 years (mean 4.8 years ago) which had allowed them to fish farther and in more challenging conditions, to save time and fuel while locating grounds and to mark their traps with discrete buoys rather than flags, reducing the risk of theft. Trap theft had apparently increased in recent years and was a serious concern, impelling fishers to fish farther offshore.

Fishers were not in agreement as to whether better catches could be obtained by travelling further and seasonal variations seemed more apparent to fishers. However, lightly or un-fished grounds were preferred and most fishers stated that they would travel further if fuel was cheaper; an indication that fuel cost was the main constraint limiting distance travelled rather than time or safety considerations. Some trap fishers claimed the potential advantages of travelling to more distant grounds were offset by increased conflicts with the industrial fleet who were repeatedly reported to encroach into the 26 mile zone reserved for artisanal fishers.

4.3. CORRELATIONS BETWEEN DISTANCE AND CATCH

Despite the large variation of lobster catches by divers, there was a significant positive relationship between expenditure on fuel and total weight of lobster caught for each of the three lobster divers examined (Figure 6, Table 2). There was also a significant positive relationship between maximum CPUE of trap grounds, as indicated by statements of "good catch" by trap fishers, and the distance of a ground from the fishers home island and Great Corn Island ($p = 0.002$). "Normal" and "Bad" catches were not significantly correlated with distance ($p = 0.150$ and $p = 0.309$ respectively).

4.4. CHANGES IN TIME

Maximum, normal and minimum distances to fishing grounds quoted by trap fishermen during interviews varied significantly with time period (p=0.000, p=0.000 and p=0.009 respectively). Inspection of the data shows that all three distances appear to have increased with time, especially during the last 10 years (Figure 7). Maximum and normal distances were significantly different between now and 10 years ago (p=0.006 and p=0.007 respectively) but not between 10 years ago and the 80s when the Bonferroni correction was applied (p=0.009 and p=0.043). The mean extension of normal fishing distance from 10 years ago to now was 10.8 ± 6.3 miles (95% c.i.) while maximum distance increased by 10.4 ± 6.9 miles.

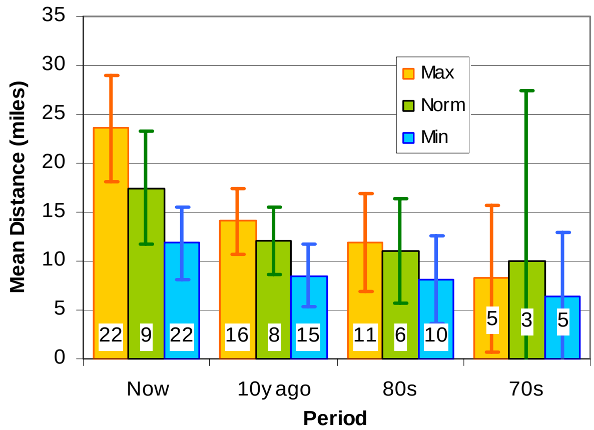

Figure 7. "Maximum", "Minimum" and "Normal" distances of fishing grounds from home quoted by Corn Island lobster trap fishermen for the past 35 years. Bars indicate mean response ±S.E. Number of responses indicated on each bar.

4.5. MICROECONOMICS OF FUEL EXPENDITURE

Balance sheets based on a typical profile of lobster and trap operations (T. Daw, unpublished data) predicted that fuel accounted for 52% of a lobster diving operation's total costs and 37% of costs of a lobster trap operation.

Diver	n	Gradient (a)	Intercept (B)	Significance
1	94 (2 removed)	0.0740	2.18	p=0.010
2	96 (5 removed)	0.0911	3.00	p=0.012
3	101 (1 removed)	0.1113	1.42	p=0.000

Table 2: Regression relationships found between daily expenditure on fuel and weight of catch for three Corn Island lobster divers between July and December 2002. (Equations are in the form: $\sqrt{catch} = a \times \sqrt{fuel\ expenditure} + B$)

The relationships between fuel and lobster diver catches in Table 2 were fed into the lobster diver microeconomic model to calculate the marginal increase in daily gross margin predicted for a 100 C$ increase in fuel expenditure (Table 3).

Incremental Spending on fuel	C$ 250-350			C$ 350-450			C$ 450-500		
Diver	1	2	3	1	2	3	1	2	3
Catch (lbs)	1.5	2.4	2.2	1.4	2.2	2.0	1.3	2.1	1.9
Catch Value (C$)	C$ 193	C$ 314	C$ 280	C$ 176	C$ 286	C$ 264	C$ 165	C$ 267	C$ 253
Catch value after deductions (C$)	C$ 166	C$ 271	C$ 242	C$ 152	C$ 247	C$ 228	C$ 142	C$ 230	C$ 218

Table 3: Improvements on gross and net revenue as a result of spending an extra C$100 on fuel by lobster divers as predicted by the regressions shown in Table 2

An increase of C$100 in fuel spending was predicted to bring an increase of C$193-253 in catch value and C$166-218 in actual revenue to the boat captain after covering costs, payments to the diver and assistant and deductions for water weight and tax.

5. DISCUSSION

Studies of fishing effort distribution generally find an aggregated dispersion [36, 42], as shown by the trap densities in this study. A regular pattern of dispersion as observed for divers is therefore unexpected and usually emerges when organisms repel each other or establish territories leading them to space out evenly [39]. Although fishermen have been reported to have territories [43, 44] examples usually concern fixed gears. Conflict between divers and trap fishers existed but it seems unlikely that there would be territoriality *between* divers who use grounds intermittently. One diver described how he usually spent half of his time at one ground, almost half at his next 3 most popular and only made occasional visits to others. This level of detail was not available for most divers, necessitating the assumption that a diver spreads effort evenly between his grounds. Temporal distribution of diver effort between grounds could be found through a logbook study as was conducted with artisanal fishers in Kenya [45] and would be expected to increase the variance and thus the dispersion coefficient of diver effort. In addition, perceptions of dispersion patterns are determined by the scale at which they are examined [46]. If divers focus on smaller grounds (e.g. individual rocks) then trap fishers examination on a smaller spatial scale may show a more aggregated distribution.

The historic extension of fishing ranges as observed in these fisheries is a typical phenomenon of fisheries as they become overexploited in nearshore grounds [47]. The extension of ranges *per se* does not definitely indicate overexploitation, as they may be due to other factors. Technological improvement (e.g. GPS) can allow fishing at greater distances; while trap fishers were impelled to travel further to avoid theft of traps. If the resource space available to the fishers is assumed to be a circle with radius equal to the maximum distance travelled, an increase in the maximum range from 14 to 24 miles over 10 years (Figure 7) would almost double the potential resource space available to fishers. It has been recognised that CPUE calculations should account for the area of grounds fished [48-50] but it also seems important to take account of changes in fished areas when following CPUE trends at one location over time. The long-term declines in CPUE of lobster in Corn Island may therefore be even more severe than fishers perceive when expansion of fished area is taken into account.

Evidence was found for increased catches with distance in both the trap and diving fishery. In the case of divers the increase in catch was demonstrated to more than compensate for the increased cost of fuel; the regression equation predicted that divers could attain higher profit margins by travelling further. This may explain why fishers have expanded their ranges over the last 10 years.

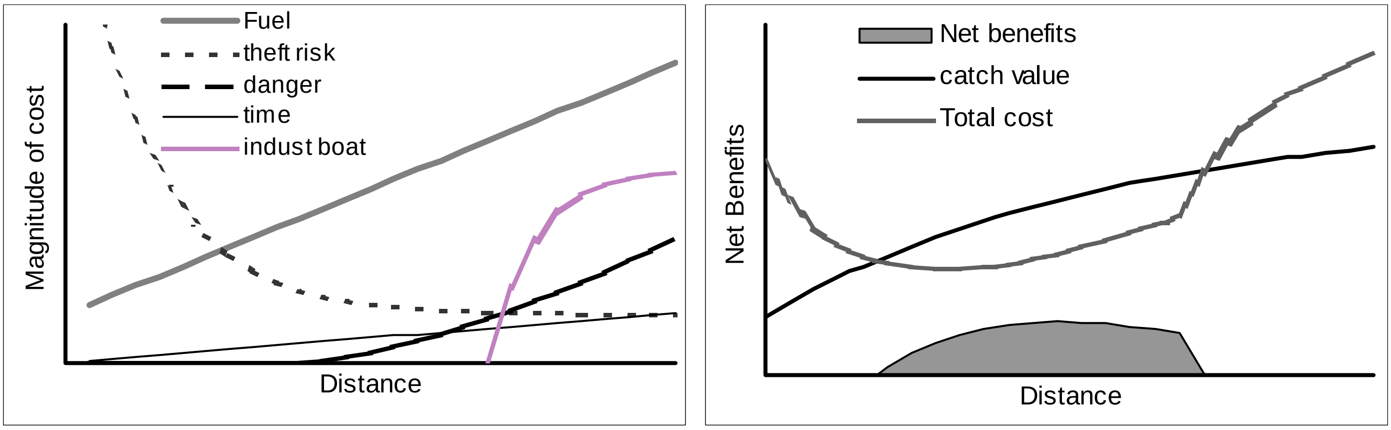

Figure 8. a) Hypothetical functions of cost with distance for a lobster trap fisherman. b) Aggregate function of total costs with distance and net revenue given an asymptotically increasing catch with distance.

However, fishers may not directly perceive or act on these relationships for two reasons:

a) The costs associated with distance do not only involve increasing fuel costs. Thus fishers are imperfectly modelled by narrowly economic equations as they take account of non-monetary costs and incentives [50]. Bene and Tewfik, for example, found that divers in the Turks and Caicos continued to exploit lobster when it made economic sense to switch to conch [51]. They were subsequently able to identify social and technical explanations for this behaviour. In the case of the Corn Islands, the decision of how far to travel to fish incorporates a range of factors, which may include extra time travelled, unfamiliarity with grounds, increased conflicts with vessels from other islands or the industrial fleet and safety issues. The recent loss of four fishers at sea emphasises the pertinence of safety concerns as an important factor. In a modelling context, one could expect each of these factors to have a different functional behaviour with distance. Figure 8(a) shows a hypothetical model of costs associated with distance for a Corn Island trap fisherman considering five of the factors discussed during interviews. When each relationship is summed to produce an aggregate cost-distance function (Figure 8b) the relationship can be seen to be much more complicated than the linear one predicted with fuel.

b) Variability in catches is considerable and influenced by the seasons and individual grounds, not only distance. It is debatable therefore, whether fishers could perceive the distance-catch relationships identified during this study. During discussions on general trends with fishers, (for example in response to the question "do you catch more when you go farther") typically they would say that sometimes catches were higher with a particular variable but that they could also be lower. Artisanal fishers elsewhere have been shown to be unable to discern spatial variation in catch rates in order to maximise their returns [36, 52]. It was also mentioned on many occasions that grounds are fished cyclically, one diver claiming he used most of his grounds only once per year. In this scenario, although a generalised trend of greater catches at more distant grounds may be observed, divers would in any one day select grounds on the basis of which had not been fished recently irrespective of distance; generalised catch distance relationships would have little impact on a day-to-day decision-making basis.

This study demonstrates a means for attaining an understanding of spatial fishing effort distribution by a low-tech and cost effective strategy of interviews. The positions plotted are likely to have several errors resulting from misjudgement by interviewees, incorrect interpretations of relative positions (section 3.2), ambiguous use of statute and nautical miles and the generalisation of potentially large, irregularly shaped grounds by the plotting of single positions. However, the accuracy is sufficient to show general patterns of effort distribution which can be used to highlight areas of potential conflict and heavy use, delineate fishing grounds, identify apparently distinct lobster stocks and indicate the implications of spatial management measures. Accuracy of the patterns observed could be tested and improved by involving more fishers, checking positions at-sea while observing fishing activities and by incorporation information on the temporal distribution of effort between sites. The effort maps produced could also be assessed and improved by incorporating data from bathymetric charts and habitat maps with knowledge of the behaviour and limitations of the fleet to "contextually edit" effort distributions, removing any grounds which had clearly been plotted in unsuitable areas. This process would benefit from the participation of a representative selection of the fishers themselves.

6. ACKNOWLEDGEMENTS

I would like to thank the many fishers, traders and residents of Corn Island for their assistance and cooperation with fieldwork, especially Norma Dixon, Jose Manuel Alvarez and Melody Taylor. Clarence Gonzalez assisted with interviews. Ulrika Gunnartz, Jessenia Bello, Karen Joseph and students from URACCAN conducted the bulk of the household survey. I am grateful to Dr. Ivan Weir for his supervision and support of the project and to Dr Bob Foster-Smith, Dr John Bythell and Michael Daw for advice on data analysis. The study was conducted as part of the Reefmap Nicaragua project funded by Rufford Small Grants, the Royal Geographical Society, Newcastle University and supported by MARENA. Tim Daw was supported by an NERC studentship travel grant.

CHAPTER 2, MAPPING AND SURVEYING

CHAPTER 2: Section A: MARINE HABITAT MAPPING

Mapping the Marine Habitats of Nicaragua's Corn Islands using a RoxAnn Acoustic Ground Discrimination System and Landsat TM Imagery

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ABSTRACT

The Corn Islands are surrounded by sediment dominated waters in an area of high rainfall. The islands' inshore coastal resources are critical to the sustainability of the islands economy and environment and are threatened by the pressures of a growing population combined with dwindling offshore fisheries. Effective coastal management needs to be supported by reliable information and undertaken with the collaboration of coastal stakeholders. With this in mind surveys were carried out to map the islands marine habitats focusing on those habitats perceived as important by the Nicaraguan government and the islands community. Landsat TM satellite imagery provided a resource for the mapping of the shallow inshore areas and this was combined with RoxAnn acoustic surveys in deeper, turbid waters to provide complete spatial coverage of the islands marine resources upto around 3km offshore. The maps were created using image processing techniques which in the case of the RoxAnn acoustic surveys required interpolation of the point survey data. There were problems with the processing of the satellite imagery due to a time lag between the date of capture and the date of the field survey (3 ½ years) which will have introduced inaccuracies into the nearshore habitat maps (>12m depth) and misclassification of algal and sand habitats in deeper waters (<12m) was a problem with the acoustic survey due to the acoustic similarity of these habitat types. The resulting maps still require an accuracy assessment before they are used for management purposes but they represent a considerable step towards developing a more strategic approach to the management of the islands inshore marine resources. They will allow decision makers to take informed decisions and will help identify important habitat, develop policies and plans to protect and conserve these areas. They may also be used as an educational resource and in support of bids to develop a well designed and long term research programme to monitor the status of the islands marine and coastal resources. The final maps and underlying data layers have been contributed in paper and geographic information system format to the Nicaraguan national and local government as well as universities and NGO's in a bid to promote data sharing and a more integrated and participatory approach to resource management on Nicaragua's Atlantic coast.

1. INTRODUCTION

Marine habitat mapping provides a spatial information background to support decision making in key areas such as biodiversity conservation, fisheries management and coastal development planning and is considered an important tool for conservation management and ecologically sustainable development [53-57]. With knowledge of the sensitivity of the habitats, a decision maker can start to assess the risk of any proposed activities, make policy and planning decisions that are better informed and can employ strategies such as multiple use zonation planning [e.g.:58, 59]. In addition to informing policy and management decisions, maps are well suited to aiding the visualisation of the natural environment and are therefore a useful resource for education and public awareness programmes and can help to communicate the rational for management and policy decisions.

1.1. THE CORN ISLANDS' CLIMATE & MARINE ENVIRONMENT:

Nicaragua's Caribbean coast has one of the highest rainfall rates in the world with an average of 3.5m per year. Peak rainfall is delivered between May and September and relatively dry season occurs between January and April [60]. However, the tradewinds blow steadily from the ENE at 7-10 m s-1, with a steadiness factor of 90% [61]. The high rainfall rates result in high levels of runoff into the coast's rivers and turbid coastal waters and although the Corn Islands are far enough offshore to avoid the sediment influence from the mainland, runoff from the islands has an influence and the tradewinds and storms also stir up seabed sediment resulting in high turbidity levels during most of the year (Velterop this study). The bathymetry of the seabed within 3km of the islands, determined from a British Admiralty Chart [62] shows the depth ranging up to 40m and previous studies reported that water transparency on the Corn Islands consistently ranges between 3m (July and November) to 25m (March and April) [63].

1.2. THE CORN ISLANDS ACTION PLAN:

In 1999, the Nicaraguan Ministry of Natural Resources and the Environment (MARENA) and the Corn Islands local government outlined their strategy for marine resource management around the Corn Islands in a natural resources action plan [17]. The plan stressed the need for current and continuing information on the status of islands' marine environment to help decision makers to assess and manage human and natural threats in order to maintain the ecological services that these marine ecosystems provide. The action plan proposed the following actions:

- Establish a programme of resource monitoring to assess changes in resources productivity and quality
- Develop fisheries management plans for the principle exploited species
- Promote the regulation of capture fisheries and encourage inter-sectoral communication and
- Establish a municipal marine park to promote the conservation of the islands' coral reefs and biodiversity.

2. AIMS

Discussions with MARENA revealed a habitat map of the islands coral reefs within a 3km of the Corn Islands would be a significant resource to help them reach the objectives set out in the Corn Islands action plan. A month was available for the field survey, with a limited budget available, so the principle aim of this project was established as:

- Rapid; course resolution mapping of the Corn Islands' islands marine habitats with a particular focus on determining the spatial distribution of the islands Coral Reef habitats.

The study also aims to assist management of the islands marine resources by assessing the local value and principle threats of each marine habitat classified in the resulting map based on a review of literature and by recommending management, research and policy options.

These habitat maps (section B) and resource assessments (section C) could assist in the identification of important sites around the islands, in the planning of well designed resource sampling and monitoring strategies and could assist with the spatial demarcation of the proposed municipal marine park and any future spatially based fisheries policy measures around the islands.

3. METHODS

3.1. REMOTE SENSING TECHNIQUES:

The only realistic way to conduct broad-scale habitat mapping surveys is by using remote sensing combined with ground validation data [64]. Satellite and airborne remote sensing platforms can provide good spatial resolution, a range of spectral information and wide-scale coverage. Their application for marine resource mapping is however restricted to shallow water environments (>25m in clear water) since the penetration of light into seawater is limited [65]. This problem is further exacerbated in turbid water environments like those experienced on the Caribbean coast of Nicaragua and opportunities for acquiring imagery with light reflected from depths up to 25m are perhaps limited to only a few days each year. Furthermore, cloud cover can obscure the area of interest in an image, further limiting the opportunities for image acquisition in these areas with high rainfall.

Mapping with Acoustic Ground Discrimination Systems (AGDS) can generate similar imagery to satellites without the restrictions of water penetration and obstruction from cloud [66]. They are also relatively inexpensive, easy to use and provide data that can be manipulated to create habitat maps using image processing techniques in the similar way to satellite image processing [see: 56, 66, 67]. AGDS was therefore an ideal option for surveying the islands' turbid deep waters. However, in shallow waters, acoustic methods are restricted due to the inability of the survey vessel to navigate shallow reefs. A combination of satellite remote sensing (for shallow waters) and AGDS (for deep waters) therefore offered a tangible approach for complete spatial coverage of the Corn Islands' marine habitats.

3.2. *RoxAnn* AGDS:

The acoustic survey was undertaken with a *RoxAnn* AGDS in collaboration with Envision Mapping Ltd from Newcastle. The *RoxAnn* AGDS is based on a single beam echo sounder and works by integrating components of the returned echoes to provide information on the acoustic characteristics of the seabed [66, 68]. In addition to the seabed's depth, the characteristics that are extracted by the *RoxAnn* system include a measure of the seabed's roughness (E1), derived from the tail of the first echo, and a measure of the seabed hardness (E2), derived from the entire second echo (which is reflected twice before returning to the transducer as seen in figure 1.) [66, 69, 70].

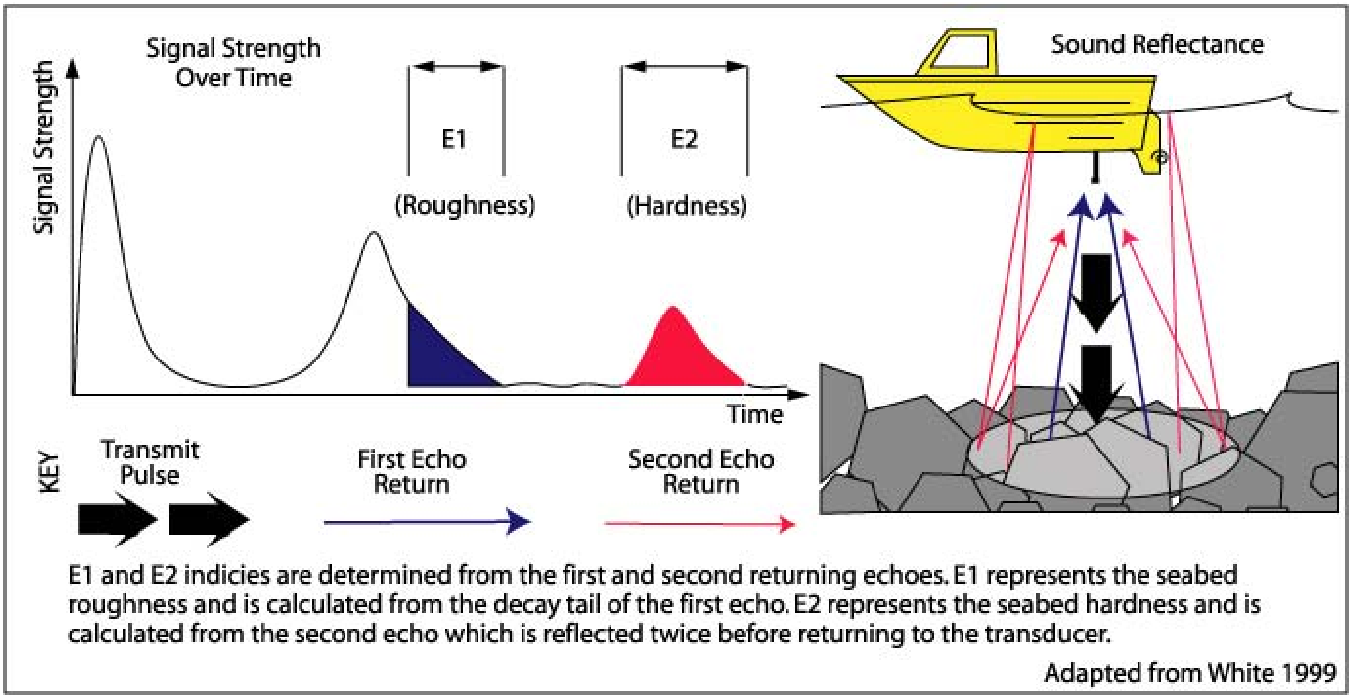


Figure 1. A diagram describing the acoustic variables recorded by a *RoxAnn* acoustic ground discrimination system.

The shape and strength of the returning echoes depends on features of the sea floor under the survey vessel and this provides the basis for data processing and habitat discrimination [71]. For example, reefs produce high E1 and E2 values. This is because the rough substrate creates significant backscatter and reflects more sound towards the transducer creating a more significant tail on the first echo, and because the substrate is hard and therefore absorbs less sound, which results in a stronger second echo. The E1, E2 and depth data along with the vessels position (from a GPS) are logged and can be exported as a text file for post processing. The data that is extracted is essentially point data centred on the survey vessel, and the acoustic 'footprint' of each point depends on the angle of the echosounder beam and the depth of the water. An acoustic 'picture' of the seabed is gradually built up by tracking back and forth over the seabed.

3.3. SATELLITE IMAGERY:

The most cost effective satellite sensors for coastal habitat mapping are Landsat TM and SPOT XS. The Thematic Mapper sensor delivers imagery with a spatial resolution of 30m and records spectral reflectance from three bands of the electromagnetic spectrum which are useful for marine habitat mapping. The SPOT XS sensor delivers a 20m spatial resolution and has 3 useful bands but is more expensive to acquire [see 65 for further details]. A search of online satellite image archives revealed that both SPOT and Landsat imagery were available. However, each of the Corn Islands was located in a different SPOT scene making acquisition prohibitively expensive. The only useable Landsat TM satellite image encompassing the Corn Islands was captured on the 25th of November 1999. The image is relatively clear of clouds and was taken during the dry season, therefore offering a greater potential for optical penetration of seawater. The image was acquired from the World Conservation Monitoring Centre and was radiometrically corrected prior to acquisition to remove the effect of atmospheric conditions at the time of capture. The turbidity of the water around the islands still limited its usefulness to shallow water (>12m) (see map 1, section B) and variability in the water clarity around the islands also meant that further image processing to remove the effect of variable water depth was not feasible. The most significant problem was the three and a half year intermission between the capture date and the survey. In this time there may have been significant variation in the distribution of the islands' shallow water habitats. There were however, no hurricanes or major storms between 1999 and 2003 and in the absence of significant environmental disturbance; coral reefs are know to be slow changing structures [72]. Since MARENA's main requirement was a map of the distribution of the islands coral reefs it was decided that the image would still prove accurate in mapping the inshore reefs and although probably less accurate it could still provide a broad generalisation of the other more variable habitats such as the seagrass beds.

4. FIELD SURVEY

4.1. LANDSAT IMAGE GEO-REFERENCING

Ground control points (GCPs) were collected at points around both Great Corn and Little Corn Island. Two GPS receivers were used in combination, and these were set to average their position over 10 minutes to ensure positional accuracy (≈ +/- 5m) using a UTM, Zone 17N projection. These GCPs were selected by observing pixels on the satellite image which could be easily discriminated. The ends of the airport runway and several piers were clearly visible on Great Corn Island as were points at the ends of the on the beaches on Little Corn Island. These points were combined with outlines of the islands' coasts, created by walking the extent of the coast and recording using the track function on a handheld GPS. Altogether, this provided adequate data to geo-reference the Landsat Image.

4.2. LANDSAT GROUND TRUTH SURVEY

A British Admiralty bathymetric chart covering an area around the islands [62] was scanned overlaid and lined up with the satellite image so that the depth contours around the islands could be approximated. For each island a mask of the deep water areas (>12m) and the land areas was constructed to restrict the area of focus to the shallow water areas. The masks were then overlaid on each of the three visible bands of the Landsat TM image and these bands were processed using an unsupervised classification method (see section 7.1. for details). This divided the image pixels from the shallow water sites into 12 classes based on their spectral reflectance values recorded by the satellite sensor. The classified maps were then used to assist the selection of sites for ground truthing surveys.

During one week of field work, data was collected from 203 sites from the shallow waters (<12m) around Great Corn Island and from 161 sites from around Little Corn Island. Time and human resources were severely limited during the surveys and so to achieve rapid data collection, an underwater video camera was used to provide basic information on the seabed type. The video camera was strapped to the underside of a kayak and recordings were synchronised with the kayak's position by using the track function on a handheld GPS unit. The time on the video tape was then cross referenced with the GPS track points and visual interpretation of the video recording provided a large amount of ground truth survey data in a short period. Each ground truth survey site was then selected from the centre of a relatively homogeneous seabed area with a span of approximately $30m^2$ to match the spatial resolution (pixel size) of the Landsat Image. Detail about the seabed habitat was then recorded (including the dominant species and the substrate type), and this data was attributed to the corresponding track point position and plotted in a geographic information system (maps 3 + 4, Section B).

4.3. *RoxAnn* AGDS SURVEY:

Acoustic surveys of both Great and Little Corn Island were made between the 10th of May and the 24th of May 2003 and covered an area of approximately 15km^2. The equipment used was a *RoxAnn* signal processor combined with a Furuno single beam echosounder and Furuno GPS (without differential correction) and the data was recorded plotted using microplot and then exported as raw text file data. The echosounder transducer was set up with a 15 degree angle, at a depth of 30m this equates to a 'sonic footprint' of fifty square meters (figure 2). A suitable vessel was acquired for the boat-work and the GPS aerial was fixed to the highest point on the vessel and the echosounder transducer was fixed to the rear of the boat using a scaffold pole. When choosing the vessel it was important to consider potential interference to the equipment such as from engine cavitations (to the transducer), heat and vibration (to the *RoxAnn* processing unit) and to ensure the protection of the equipment from the elements. To ensure the security of the equipment the system was set up daily during the survey. Each day the unit was calibrated so that the E1 and E2 data was roughly the same for an area of flat seabed near the harbour site. The dominant wind and wave direction on the islands is NE–SE and based on what could be seen on the satellite image, local knowledge about the position of the islands coral reefs and preliminary scuba diving observations, the surveys initially concentrated on the north side of the islands to ensure coverage of the coral reef habitats. During the survey the output signals (position, depth, E1 and E2) were monitored and areas of interest (with high E1 and E2 values and variable depth) were noted, along with any potential erroneous data points. The data was exported as a text file daily and plotted onto the satellite image in a GIS. The roughness and hardness datasets were displayed as thematic layers in order to identify possible areas of coral reef and this helped to plan the next day of surveys.

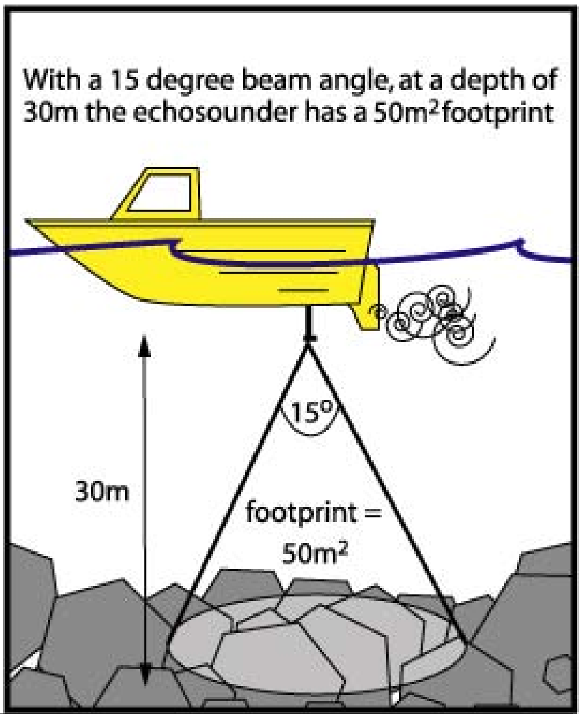


Figure 2. A diagram describing the acoustic footprint created by a single beam echosounder.

4.4. *RoxAnn* GROUND TRUTH SURVEY:

The *RoxAnn* ground truth survey during the acoustic study was carried out using a miniature digital camera or 'web cam' housed inside a dive torch. This was powered by a 12V battery along a 30m cable and the signal was transmitted back along the same cable and via a USB lead to a laptop computer. This was a low cost approach to ground truthing and although the image captures were low resolution, the real time video output was effective and enabled notes to be taken on the dominant species and substrate during the surveys. Some of the ground truthing was done at the time of the AGDS survey but it was a time consuming process and stopping the vessel to obtain a sample interfered with the acoustic signal recording. Most of the ground truth data was therefore collected after the initial ADGS survey. The data from the AGDS survey was plotted on a GIS and a handheld GPS was connected to the computer to plot the position of the boat on the same map. The E1 and E2 values for each point were displayed in the GIS as a thematic layer and this helped to guide to vessel to different habitats. Detail about the dominant species and the substrate was recorded for each site and this was stored in a database along with the capture images for later use in habitat classification (see maps 3 + 4, section B).

5. HABITAT DEFINITION

Ideally, a habitat map classification scheme should be based on a quantitative assessment of marine field survey data to avoid misclassification and ambiguity [73, 74]. The lack of existing multi-habitat, quantitative data on the marine environment surrounding the Corn Islands and restrictions on time and resources to collect extensive data meant that the classification scheme for this study was adapted from an existing habitat scheme developed for the Caribbean [73: table 1]. This scheme was developed in a similar Caribbean marine environment (Belize) and is hierarchical and therefore allows the user to choose different levels of descriptive resolution depending on the objective of the study.

Table 1. Regional classification scheme developed using Belizean survey data by Mumby and Harborne [73].

First tier		**Second tier**		**Third tier**	
Code and label	Characteristics	Code and label	Characteristics	Code and label	Characteristics
1. Coral classes	>1% hard coral cover	1.1. Branching corals 1.2. Sheet corals 1.3. Ribbon and fire corals with green calcified algae	*Acropora spp.* visually dominate *Agaricia spp.* visually dominate *Agaricia tenuifolia* visually dominant	1.4.1. Sparse massive & encrusting corals 1.4.2. Dense massive and encrusting corals	1±5% hard coral cover >5% hard coral cover
2. Algal dominated	>50% algal cover; <1% hard coral cover	2.1. Green algae 2.2. Fleshy brown algae and sparse gorgonians 2.3. Lobophora 2.4. Euchema & Amphiroa	=3 gorgonians m^2 Monospecific Lobophora beds Rare assemblage dominated by red algae & encrusting sponges		
3. Bare substratum dominated	Dominated by bare substratum; <1% hard coral cover	3.1. Bedrock/rubble and dense gorgonians 3.2. Bedrock/rubble and sparse gorgonians 3.3. Rubble and sparse algae 3.4. Sand with sparse algae 3.5. Mud 3.6. Bedrock	>3 gorgonians m^2 (usually >8 m^2) & ca 30% algal cover =3 gorgonians m^2 and little algal cover No gorgonians >90% sand		
4. Seagrass dominated	>10% seagrass cover	4.1. Sparse seagrass 4.2. Medium density seagrass 4.3. Dense seagrass 4.4. Seagrass with distinct coral patches	Standing crop 1±10 g.m ^{2}; cover <30% Standing crop 11±80 g.m^2; cover 30±70% Standing crop >80 g.m^2; cover >70% Seagrass visually dominant, coral cover may reach 3%, gorgonians may be present.		

The course resolution classification level of this scheme was envisaged for use with the Landsat TM sensor. Optical sensors such as Landsat TM have difficulty in distinguishing between habitats that have similar optical properties (e.g. algae growing on bedrock and algae growing on sand) whereas AGDS is more likely to be able to discriminate between habitats established on different substrates because of their differing acoustic properties. Grouping these habitats was therefore likely to confuse the acoustic classification. For example, mud and dense gorgonians have very different acoustic properties. Gorgonians growing on rubble have quite a distinct acoustic property because of their high profile and rugosity and the hardness of the rubble substrate, producing high E1 and E2 values, whereas mud absorbs sound producing a very low hardness (E2) value and is very flat also producing a very low roughness (E1) value. An intermediate classification level was chosen which split the bare substrate dominated class. Rubble and algae and rubble and sparse gorgonians are grouped into a new class based on their similarity and dense gorgonians, sand, bedrock and mud were all added as separate classes. However, in the ground truth surveys only bare sand was found and so bedrock and mud were discarded leaving six classes for the final scheme (table 2).

1. Coral Reef	>1% hard coral cover
2. Sand and Algae	>10% algal cover; <1%hard coral cover
3. Seagrass	>10% seagrass cover
4. Rubble, Algae and Seafans	>3 gorgonians m^2 (usually >8 m^2), ca 30% algal cover,
5. Rubble and Algae	<=3 gorgonians m^2 >10% algal cover
6. Sand	>90% sand, < 10% algae
7. Mud	Discarded
8. Bedrock	Discarded

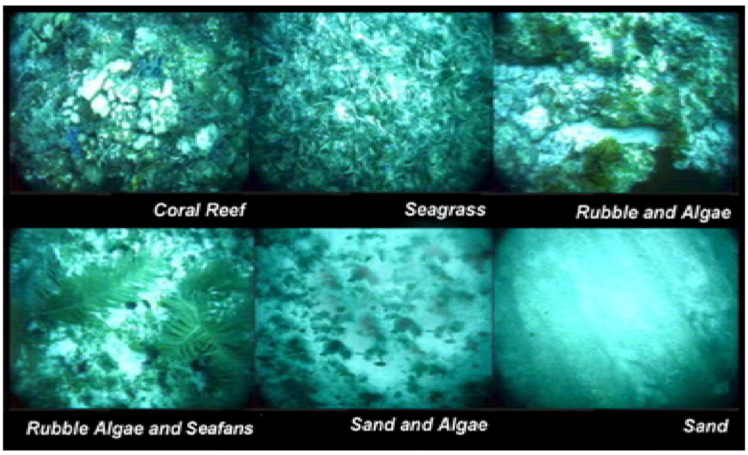


Table 2. The adapted classification scheme used in this study and examples of the six classes obtained during ground truth sampling.

5.1. PARTICIPATORY HABITAT ASSESSMENT

In choosing a classification scheme which integrates both acoustic and optical methods it needed to be comparable for both types of survey as well as meeting the objectives of the study (i.e. course resolution mapping of the islands' marine habitats) [73]. The main use of the map is likely to be zonation planning and because zonation may effect the livelihoods of local stakeholders the perceived value of the different habitats was taken into account during a workshop with community members. Local community members (mainly fishers) were presented with the proposed classification scheme and information on the importance of the various ecosystems as reviewed in scientific literature. This combination of local perceptions and scientific review ensured that the classification scheme included habitats deemed important by some of the local community and a rapid review of local perceptions of the threats to these habitats and potential management options is included with the resulting maps to help direct resource management and planning. It should be emphasised that this was by no means a representative survey of perceptions but rather a rapid review of interested stakeholders. It became evident during this workshop and during the preceding literature review that the algae and sand and algae and rubble habitat classes have similar uses and threats and so they are grouped in this review. However, there may be advantages to a separate classification of these two classes that were not observed initially so in the classification scheme the two classes are kept separate. The resulting assessments are included in section C and are summarised in table 3 below:

Habitat	**Coral Reefs**	**Seagrass Beds**	**Algal Habitats**	**Rubble, Algae & Seafans**	**Sand**
Existing Use / Local Value	Lobster Habitat, Fish Habitat, Coastal Protection, Bio-diversity, Eco-tourism, Dolphin Habitat,	Lobster Habitat, Fish Habitat, Coastal Protection, Turtle Habitat, Dolphin Habitat, Waste Treatment (Water Quality),	Lobster Habitat (Juvenile), Waste Treatment (Water Quality),	Lobster habitat, Fish Habitat, Dive Tourism,	Lobster Fishing Areas
Possible & Potential Uses	Hawksbill Habitat, Curio Trade, Aquarium Trade, Bioprospecting, Coral Mining, Waste treatment,	-	Seaweed Farming	Aquarium Trade, Curio Trade, Bioprospecting,	Artificial Reefs, Seaweed Farming
Existing Threats	Nutrient Enrichment, Sea level Rise, Over Fishing, Sedimentation, Destructive Fishing, Pollution Marine Debris, Alien Species, Physical Damage, Coral Disease	Sedimentation, Shading, Mechanical Damage, Pollution,	Sedimentation, Smothering, Mechanical Damage,	Mechnical Damage, Pollution, Disease,	-
Potential Threats	Intensive & Destructive Collection (Aquarium Trade, Curio Trade, Coral Mining, Bioprospecting)	Aesthetic Removal, Disease,	Invasive Species	Intensive Collection	Invasive Species,
Research & Management	Reef Monitoring Biodiversity Assessment, Strategic Research, Education & Codes of Conduct, Waste Management & Technical Advice, Fisheries Management, Zonation Planning, Pollution Clean Up, Contingency Plan, EIA requirement	Nursery habitat desk study, Assessment of Mechanical Damage, Study of Impact of Lobster Traps, Soil Management, Eco-tourism economic study, Pollution management	Monitoring, Spiny Lobster Recruitment Study, Waste & Pollution Management EIA, requirement	Lobster & Fish Recruitment Study, Waste & Pollution Management Biodiversity Assessment, Zonation Planning, EIA requirement	Desk & Field Studies of Artificial Reefs and Seaweed Farming EIA requirement

Table 3. A summary if uses, threats and management recommendations for the Corn Islands marine habitats derived from a combination of reviewed scientific literature and a rapid assessment of local perceptions.

A number of reoccurring management themes emerged during the habitat assessments which have implications for the potential uses of the resulting maps and these are discussed further in section C.

6. DATA PROCESSING

6.1. *RoxAnn* DATA EDITING:

The first stage of data processing for the *RoxAnn* data is to remove all rogue data that may affect the accuracy. The data was imported as a text file into an Excel spreadsheet from the Microplot recording software. RoxAnn data contains erroneous data due to the presence of fish or other interruption failure which cause data spikes [75]. During the surveys on the Corn Islands, there was an abundance of *Sargassum spp.* floating on the surface, which frequently caught around the echosounder transducer causing some disruption to data recording. Positional errors were also observed during the survey because of deteriorating GPS signal quality which caused skips in the position data. These errors are easily identified and removed by calculating the standard deviation of each depth and position variable (Depth, Latitude & Longitude) including each data point and adjacent points in the calculation. High standard deviation values reveal spikes in the data and these points can then be evaluated to ensure that they are indeed spikes caused by error (and not seabed features) and the entire record can then be deleted. E1 and E2 values are also influenced by variation in the speed of the vessel and can increase if the vessel slows or comes to a stop [67]. Data associated with low vessel speeds was therefore deleted by calculating the distance between consecutive data points using equation 1 below.

$$\text{Distance} = \sqrt{(\text{Easting1} - \text{Easting2})^2 + (\text{Northing1} - \text{Northing2})^2}$$

Equation 1. Calculation used to remove spurious position spikes.

All points that were less than 3m apart (indicating slow vessel speeds) were then deleted. Following this data cleaning process, the positional data was then converted to a Universal Transverse Mercator (UTM) projection (Zone 17N) with a WGS 84 datum. The depth data is usually corrected to chart datum using a tidal prediction programme [67] but this could not be carried out because of a lack of information on local tidal conditions.

6.2. *RoxAnn* DATA STANDARDISATION:

Variation of the *RoxAnn* E1 and E2 data on different days at the same sites was sometimes significant for the AGDS survey on the Corn Islands, probably because the *RoxAnn* equipment was removed and setup each day and calibration of the unit each day was not effective. However, even though there was variation in the magnitude of the E1 and E2 values it is reasonable to assume that the AGDS responds to the ground types in the same way [67]. The surveys on each island started from the same point each day and overlapped in several places on consecutive days. Variations in datasets could therefore be dealt with by transforming each dataset so that the overlapping areas agreed with the previous day's survey thereby transforming all of the data so that it conforms to the first day's survey. This was achieved by plotting each day's data in turn in *MapInfo* with the previous days. A spatial query was then used to extract data from each data set in areas which overlapped. In each overlap area, the E1 and E2 data was divided by the previous day's data, and by averaging the degree of change, transformation functions were calculated. This was then applied to the second dataset. Following the standardisation process, the datasets for each day were combined for each island. The standard deviation of the depth value over ten *RoxAnn* points was calculated (as a fourth variable) to give a further estimation of the rugosity of the seabed to be used in image classification. For example, a coral reef habitat would have a high standard deviation of depth (SDdepth) as reef pinnacles project out from a flat seabed, whereas a sand or seagrass habitat would have minimal standard deviation. The final position of the *RoxAnn* tracks is shown in map 2: section B.

6.3. *RoxAnn* DATA INTERPOLATION

In order to use image-processing techniques to classify the RoxAnn data in a similar way to optical remote sensing imagery, continuous images of the acoustic variables were produced from the RoxAnn tracks. A method called interpolation were used to estimate E1, E2, depth and SDdepth values at positions in between the RoxAnn data points based on the existing data values. Interpolation creates a regularly spaced grid of data values and this grid is then transformed into a surface plot to create a continuous image. There are a number of different interpolation methods and options offered by geostatistical packages such as *Surfer* and *Vertical Mapper*. In this instance, *Surfer* was used and an inverse distance squared algorithm was applied to each acoustic variable with a grid spacing of 30m x 30m. The inverse distance to a power interpolation method assumes that the estimated value is a distance weighted average of the existing data within the search radius. For Little Corn Island the search radius was set to 700m and for Great Corn Island, it was set to 450m. This allowed for complete coverage of the survey area based on the available data. The result of the interpolation process is the generation of four images; one for each *RoxAnn* acoustic variable (E1, E2, Depth and SDdepth). A detailed assessment of interpolation methods and their use in *RoxAnn* data analysis is provided by Foster-Smith [67].

6.4. IMAGE ENHANCEMENT

Image enhancement is required to increase the contrast of each image to spread the range of pixel values across the available range of grey tones (0-255 in n 8 bit image) to make full use of the display scale [76]. Following the interpolation of each of the *RoxAnn* variables in *Surfer* the *RoxAnn* the resulting images were imported into *IDRISI* and a linear contrast stretch applied in preparation for the classification process. The linear contrast stretch re-scales the minimum pixel to zero and the maximum value to 255 and spreads the intermediate pixels evenly through the display scale in relation to their original positions.

Before the satellite image bands could be stretched, they required special attention. Firstly the image was cropped to create separate images for each island. A mask was then constructed to cover the deep water areas and land areas in *IDRISI*. A British Admiralty Chart [62] was georeferenced and by digitising around the 12m contour and the edge of the image a polygon was created covering the deep water areas. This polygon was then overlaid on the satellite image and then an additional polygon was digitised over the land and any clouds. The polygon vectors were then reformatted as raster images and a value of 1 applied to the background and 0 to the masked areas creating a Boolean image for each island. This image was then applied to each band in the satellite image using *IDRISI's* multiplier overlay function, resulting in six masked images, (one for each band for each island). These masked images were subsequently stretched using a linear contrast stretch in the same way as the *RoxAnn* images.

7. IMAGE CLASSIFICATION

Multispectral classification is a computer based method where a number of wavebands (in the case of Landsat TM – 3 wavebands) are input into a statistical clustering algorithm which organises the individual pixels from the image into distinctive groups (classes) which are assumed to represent specific habitat types [74]. Using interpolation to create continuous images of *RoxAnn* AGDS variables (E1, E2, depth, SDdepth) enables this same process of multispectral classification to be applied to the acoustic survey data [for a detailed review see: 56, 67]. Following the preceding process of radiometric correction, georeferencing, masking and stretching for the satellite imagery and data cleaning, transformation, interpolation and stretching for the *RoxAnn* data the imagery was ready for classification. Image classification involves three stages: training, signature evaluation and decision making. The training process defines the spectral, or in the case of *RoxAnn*, acoustic envelope of each class. The coral reef class for example has minimum and maximum pixel values in three wavebands of the Landsat data and these values define a three

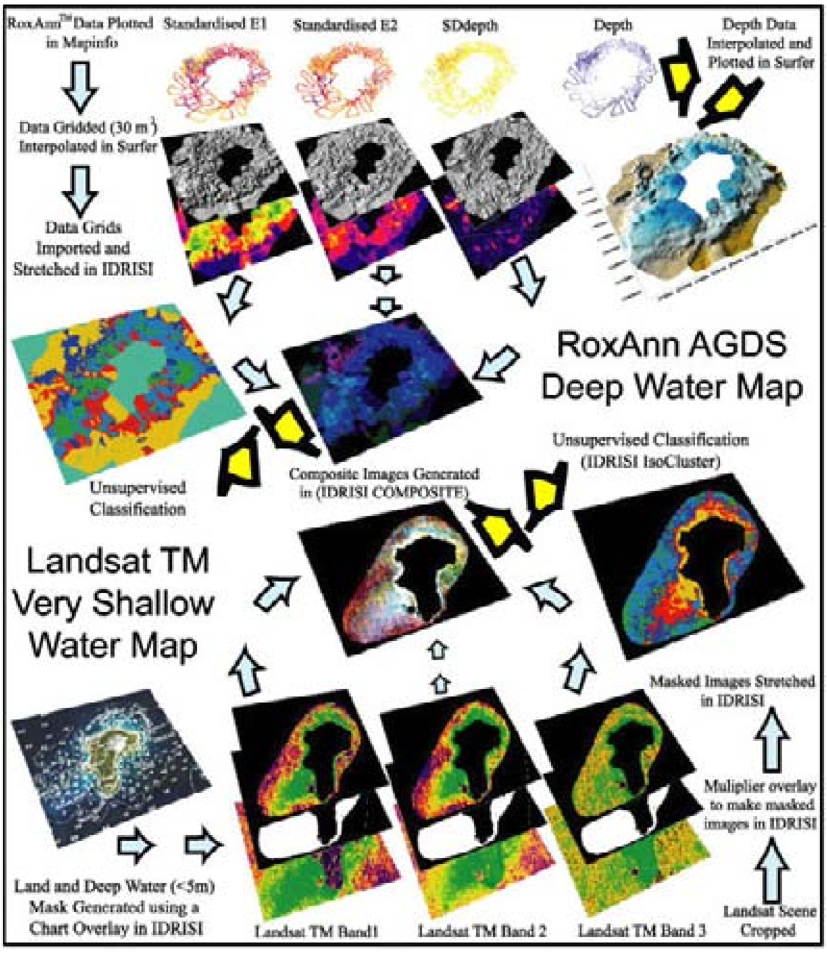


Figure 3. An illustration of the image processing steps required to produce the unsupervised classifications of Corn Island from Landsat Imagery and *RoxAnn* AGDS data.

dimensional spectral envelope. This spectral envelope is termed the 'signature' for that class. Signature evaluation is a process of ensuring minimal spectral or in the case of *RoxAnn*, acoustic overlap of these signatures to avoid confusion in the classification process. Decision making is the process of sorting the image pixels into the classes defined by the signatures and is carried out using mathematical algorithms termed 'decision rules' [74].

7.1. UNSUPERVISED CLASSIFICATION:

Unsupervised classification is a process of data clustering whereby the computer looks for natural concentrations of pixels (clusters). These clusters may be used as an approximation of the habitat distribution and the process was therefore useful in helping to guide the ground truthing surveys to areas where different habitats are likely to occur. Figure 3 shows the steps involved in producing the unsupervised classifications for Great Corn. After preparing the imagery, the clusters were produced by running an iterative self organising clustering process in *IDRISI* (ISOCLUST) which is similar to the ISODATA routine developed by Ball and Hall [77]. For each *RoxAnn* and Landsat map, a false colour composite image was constructed to seed the clustering process. The number of clusters was set to twelve (twice as many as required) allowing a greater degree of interpretation of the resulting classification. The computer then calculates the mean values of these twelve clusters (which are selected by the computer systematically based on regions of high frequency values). Each pixel in the image is then assigned to the nearest cluster based on its spectral (or acoustic) value and the process is repeated for a set number iterations (in this case three) and each time the computer slightly adjusts the clusters, improving the classification [for a more detailed explanation of unsupervised classification see: 78]. The resulting classes were interpreted as an estimation of the location of different habitats which could then be utilised in planning and directing the ground truth surveys.

7.2. SUPERVISED CLASSIFICATION:

7.2.1. TRAINING:

In the case of supervised classification the signatures for each class were defined from the ground truth surveys (training sites) and are defined using the six classes from the habitat classification scheme (see section 5). The ground truth data was plotted in a GIS (*MapInfo*) and a numerical habitat code (1-6) based on the classification scheme was assigned to each point. Each of the points was then buffered with a 30m diameter circular polygon to approximately match the pixel size of the Landsat images and the grid size of the *RoxAnn* images. A vector layer for each *RoxAnn* and each Landsat map were created using this process. These were then exported from *MapInfo* as map interchange files (*.mif*) and then imported into *IDRISI* as vector files. See maps 3 + 4 in section B to see the number of and location of training sites around Great Corn and Little Corn.

The MAKESIG module in *IDRISI* was then used to construct signature files from these *IDRISI* vector files for use in the classification process. For the *RoxAnn* image classifications the four acoustic variables were used (Standardised E1 and E2, depth and the standard deviation of depth) to define six, four dimensional signatures (one for each class) for each of the islands. Similarly, for the Landsat satellite image classifications the three optical wavebands of the Landsat Image were used to define six, three dimensional signatures for each island. The MAKESIG module generates a signature file (.sig format) for each class which contains details about that signature including the minimum, maximum, mean average and variance values for each band used in the signature. Prior to carrying out the decision making process the signature files were first analysed (using the SIGCOMP module in *IDRISI*) to assess the amount of overlap between different signatures. Overlap in the signatures leads to ambiguity and misclassified habitats in the final habitat map and therefore a reduction in the overall accuracy of the map.

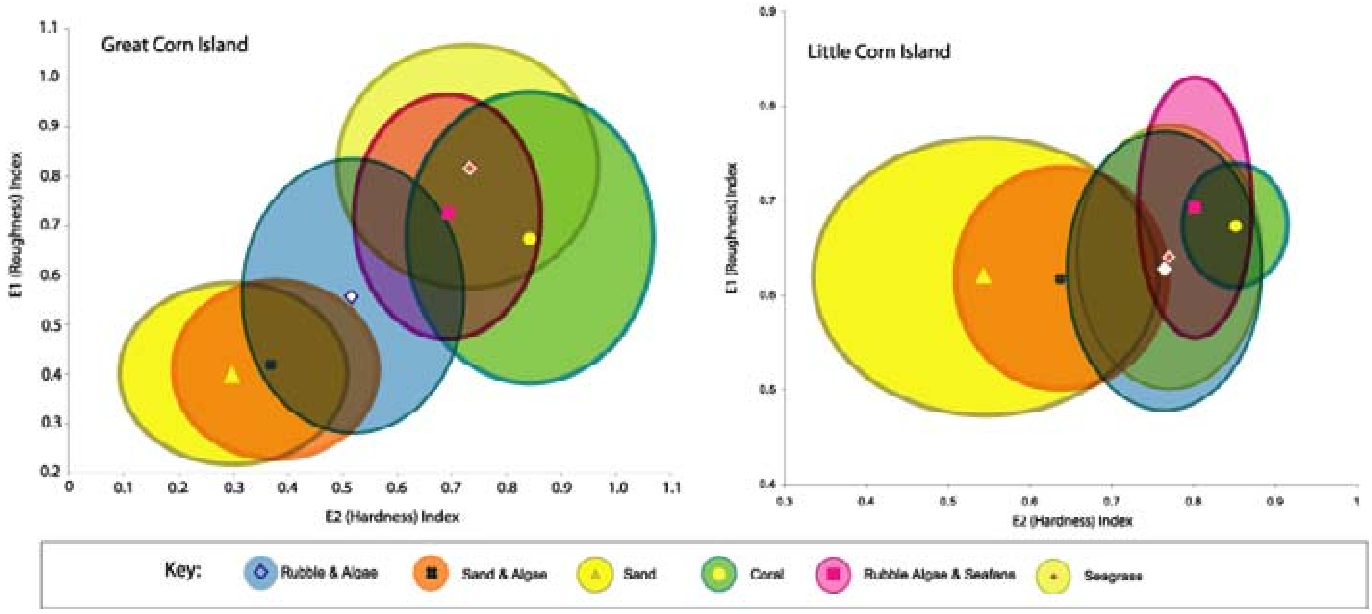
7.2.2. LANDSAT SIGNATURE EVALUATION:

Analysis of the signatures for the Landsat Imagery revealed significant overlap in the signatures for the algal classes (algae & sand, algae & rubble, and algae & seafans). Signature confusion was expected to be a problem because of the optical similarity between these habitats. However, even after these habitats were combined into a new algal class there was still significant signature overlap with the other classes due to a large variability in the pixel values in this combined signature. It was assumed that this variability was due primarily to habitat change between the date of image capture and the ground truth survey date (resulting in signature overlap). For example, if at the time of capture some sites were algal habitats but these had changed since and were subsequently recorded as sand during the ground truth survey, this would increase the variation in the algal signature and cause a significant overlap with the sand signature. This made it impossible to make an accurate map classification based on the Landsat image, however it was decided that most of the habitats were likely to have remained unchanged, especially the coral reef habitats which change slowly in the absence of storm disturbances [72].

7.2.3. SIGNATURE RECTIFICATION / ONSCREEN DIGITISATION:

Assuming that signature overlap was due to misclassification, two options were determined to partially rectify the classification. The first option was to overlay the ground truth data on the satellite image in *MapInfo* and to delete any points that are obviously inconsistent with the underlying image data and then trace around the habitats using onscreen digitisation and visual interpretation, utilising the remaining ground truth data as a guide for manual classification of the habitats. The second option was to delete any inconsistent data points as before in an attempt to reduce the variance for each signature and then to reclassify the images using these edited signatures. Both options would lead to inaccuracies in the final maps which would be more accurate in reflecting the habitat distribution at the time of image capture (1999) but this was unavoidable given the resources available for the study. It was decided given the large amount of ground truth data available and the small inshore area to be mapped around little Corn Island it was easier to classify the shallow water areas using visual interpretation. However, for Great Corn Island, digitisation would have taken a long time and not as much ground truth data was available in terms of spatial coverage making visual interpretation more difficult, so the second option of reclassification was used to produce the final Landsat map. Rather than merging the algal classes in this classification which would lead to a high spectral overlap and signature confusion, the classification was still undertaken with six (edited) signatures and the classification was contextually edited later after being merged with the *RoxAnn* classification.

7.2.4. *RoxAnn* SIGNATURE EVALUATION:



N.B.: The points represent the mean of each signature and the ellipses represent one standard deviation.

Figure 4. Charts representing the E1 (roughness) and E2 (hardness) indices for each of the habitat signatures used in the supervised classification of the *RoxAnn* AGDS data.

Overlap between signatures was also a problem for classification of the *RoxAnn* imagery. Figure 4 shows two dimensions (E1 & E2) of the *RoxAnn* signatures for Little Corn Island. These charts were constructed by overlaying the ground truth polygon layer on top of the *RoxAnn* survey data in *MapInfo* and then extracting (using a spatial query) the E1 and E2 values under each polygon. The data was then exported to Excel in order to calculate the mean and standard deviation of each signature.

A similar amount of ground truth data was used to create the signatures for each island except for the coral reef signature for Little Corn (only 8 sites compared to 23 for Great Corn) which might explain the much wider variation in the reef signature (see maps 3 + 4 in section B) to see the ground truth data used). It is clear that there is significant overlap between the signatures on both islands. The sand and algae signature is almost identical to the sand signature and there is also significant overlap with the rubble and algae signature. On Little Corn the seagrass signature is almost identical to the rubble and algae signature but on Great Corn there is minimal overlap in these signatures which might be due to differences in the composition and density of the seagrass habitats on each of the two islands. On both islands the seagrass habitat signatures also overlaps with the rubble, algae and seafan signature. In these two bands the coral reef signatures also have significant overlap with all of these habitats on both islands.

However, although there is significant overlap in the signatures using the E1 and E2 bands adding the depth variable does decrease the signature overlap to some degree because depth is very important in structuring biological communities. Habitats are therefore distributed at different levels along this gradient. The standard deviation of depth also dramatically decreases the signature overlap for the coral reef class and ensures a much higher accuracy of reef habitats than other classes because coral reefs generally have high depth variability. Using the standard deviation of the depth variable did not significantly improve the problem with the overlapping algal or sand signatures as they are fairly flat habitats.

Contextual rules were therefore developed in order to edit the final map based on the environmental conditions required for the growth of different habitats. Seagrass beds for example grow well in sheltered areas and are therefore unlikely to be extensive on the North East sides of the islands beyond the fringing reefs where they are subject to wave energy; areas classified as seagrass here are therefore more likely to be rubble and algae. In contrast seafans grow in areas of high wave energy and are therefore unlikely to grow in sheltered areas. The contextual editing rules used in the editing of the final habitat map are outlined in section 2.6 and 2.7.

7.2.5. DECISION MAKING:

A number of decision rules are available for undertaking a supervised classification including a non-parametric approach (parallelpiped) which allows the user to set the class for overlapping signature areas and several parametric rules (minimum distance, mehalanobis and maximum likelihood) which classify all the pixels using statistical similarity [78]. The maximum likelihood classification is the most sophisticated of the parametric decision making rules as it takes into account the most variables [74]. This maximum likelihood classification module in *IDRISI* (MAXLIKE) was used in the supervised classification. The probability that each pixel is associated with a particular training site signature is taken into account in the maximum likelihood classification process as well as the variability of each class. The classification process can also be weighted in favour of a particular class using weighted probabilities. The probabilities for a class are weighted for the entire image by inserting a higher percentage value for that class or if it is believed that there is a higher probability that the pixels will be a certain class in a certain area (such as seagrass rather than sand and algae in sheltered areas) a higher probability can be in that area using a prior probability image [77]. Considering the confusion in the signatures this was an option, but it was decided that the probabilities should be set as equal in the classification process, favouring a process of contextual editing of the final classification.

7.2.6. CONTEXTUAL EDITING & OVERLAY: GREAT CORN ISLAND

Editing the Landsat ground truth data for Great Corn Island greatly improved the supervised classification. However, spectral confusion was still a problem between the rubble, algae & seafan (RAS) class, the seagrass (SE) classes, between the sand & algae (SA), and rubble & algae (RA) classes. This resulted in areas of being classed as RAS on the northern and eastern sides of the island in shallow inshore areas behind the fringing reef. This is unlikely because seafans require high current areas whereas seagrasses grow in sheltered habitats. These areas were therefore reclassified as SE. The conflict between SA and RA habitats were more difficult to deal with. Almost all of the inshore algal habitats were classed as rubble & algae but there is little difference in the conditions required for their growth so a contextual editing rule could not be formulated. The assessment of habitat use and value did however indicate that they have similar uses. Misclassification is not therefore seen a serious issue from a management point of view. This should be noted however, when considering the accuracy of the Landsat map within the 12m contour. The *RoxAnn* signatures for sand & algae, and rubble & algae are much clearer because of the differing acoustic properties of these habitats. The *RoxAnn* classification produced mainly rubble and algae classes in nearshore areas adjacent to the Landsat derived habitats which allowed the maps to be merged easily in these areas. In deeper waters the Landsat classification seemed to produce an 'edge' of rubble, algae & seafans (RAS) which was probably due to a lack of depth invariant processing. In overlap areas between *RoxAnn* and Landsat where there was conflict between the classifications the *RoxAnn* classes took precedent (and were overlaid on the Landsat classes), which resulted in editing out this RAS 'edge' because of a higher confidence that the *RoxAnn* survey could distinguish these habitat classes. In the *RoxAnn* classification there was almost complete overlap between the sand and the sand & algae signatures but there was no way of editing these based on a contextual rule so this ambiguity remains in the final *RoxAnn* classification.

7.2.7. CONTEXTUAL EDITING AND OVERLAY: LITTLE CORN ISLAND

Using digitisation to classify the Landsat habitats on Little Corn Island may have been a more successful approach to classification for the Landsat data. There were no rubble, algae and seafan sites observed during the Landsat ground truth survey on Little Corn so this class was omitted from the inshore habitat map. The remaining five classes were fairly easy to distinguish from visual inspection of the image using the ground truth data as a guide. This process was carried out with the *RoxAnn* map overlaid on the satellite image which made it easier to observe and rectify any conflicts with the *RoxAnn* classification. Very little contextual editing was carried out on the *RoxAnn* classification for Little Corn, although there was signature overlap between the seagrass (SE) and rubble, algae & seafan (RAS), and rubble & algae (RA) habitats all of the SE habitats were located in the sheltered western side of the island which was inline with the ground truth data. However, there is still ambiguity between the RAS and RA habitats on the eastern side of the island. In addition there was also complete signature overlap between the sand and the sand & algae habitats in deeper waters and as with Great Corn this ambiguity remains a problem which could not be rectified using contextual editing.

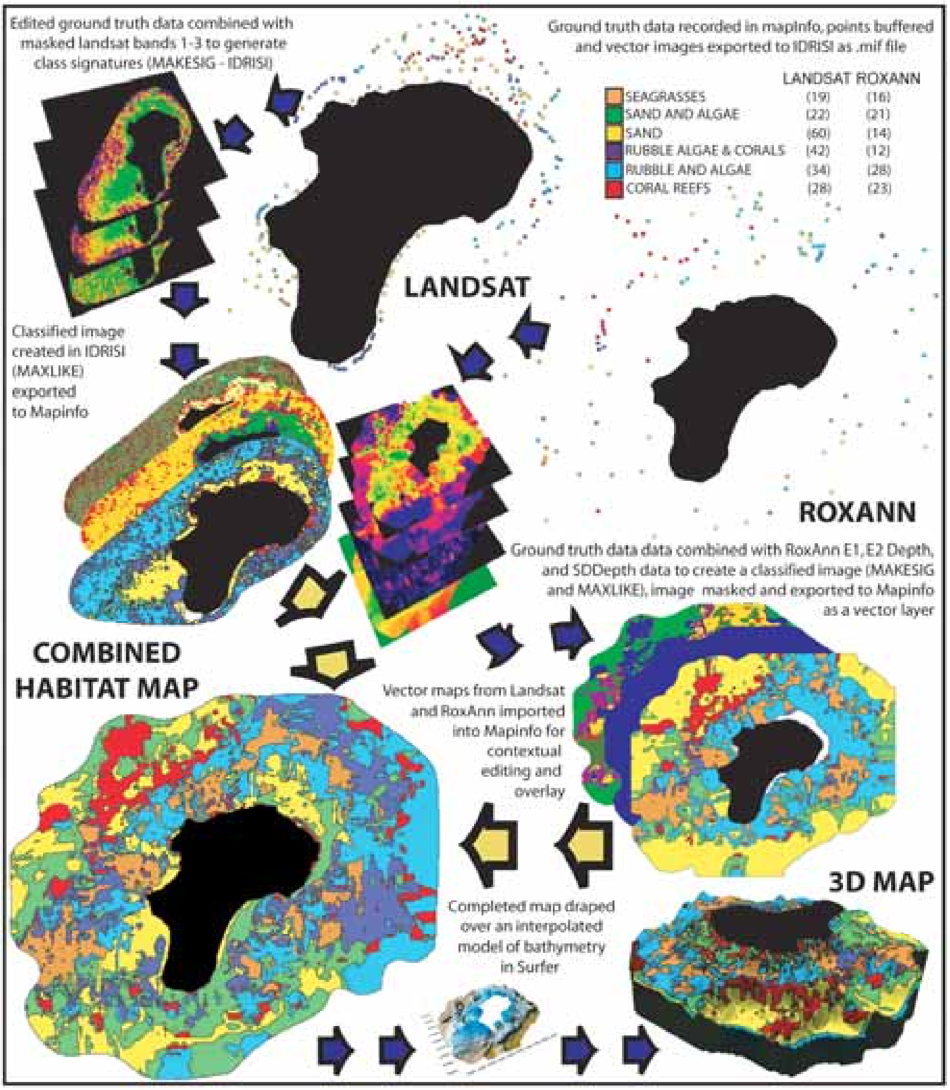


Figure 5. An illustration of the image processing and editing steps involved in the production of the final supervised classification for Great Corn Island.

8. FINAL MAP PRODUCTION

Following the supervised classification and editing processes the final maps were exported to *Surfer* where for final map production. In *Surfer* a title, class legend, scale and grid were added to each of the maps. Three dimensional habitat maps were also constructed for each of the islands by overlaying the habitat maps onto models of bathymetry generated from the *RoxAnn* surveys. These may help in the interpretation of the map enhancing their educational value. All of the habitat maps produced for the Corn Islands are located in section B.

9. DISCUSSION

9.1. LIMITATIONS OF *ROXANN* AGDS:

As outlined earlier, the *RoxAnn* AGDS processing unit utilises a single beam echosounder. The area ensonified by this echosounder varies depending on the depth of the water. This means that the E1 and E2 values derived from the *RoxAnn* unit are likely to be produced from a mixture of substrates unless the area is very homogeneous. This problem is also likely to increase with depth because the area ensonified also increases with depth. Heterogeneity and depth therefore dictate the classification accuracy [69]. A number of other factors can cause spurious E1 and E2 values during the *RoxAnn* survey. Sharp turns can cause an increase in hull cavitations and tendency for the vessel to roll and increased vessel speed results in greater distance between the survey points which can affect the dataset [79]. These problems were hopefully avoided during the survey by maintaining relatively slow survey speeds (around 4-5kts) and deleting data from slow vessel speeds (e.g.: during turns). There is a possibility that spurious data might have remained in the final dataset used in the classification. A further potential problem with the survey was that the equipment was setup and taken apart each day. This might have resulted in inconsistencies in the data due to variations in the position of the transducer. This problem was mitigated by ensuring consistent positioning and setup. Variation is therefore not believed to have caused any significant errors. Vibration and temperature may have affected the electronics whilst onboard the survey vessel but again no major unexplained fluctuations were observed and the equipment was setup in the cabin of the vessel and was well protected from the elements.

9.2. LIMITATIONS OF THE POSITIONING SYSTEM:

The accuracy of the GPS system used is a limiting factor in the study. Differential receivers were not used in the *RoxAnn* surveys or the ground truthing surveys. However, even without a differential receiver GPS accuracy is likely to be within the range of +/- 5-10m. The combined positional error for the *RoxAnn* survey and then for the ground truth survey increases the envelope of uncertainty to +/- 10-20m [80]. Additional positional inaccuracies also arose during the ground truth survey because a drop down camera was used which may have drifted away from the vessel during the sampling. In the case of the *RoxAnn* surveys a further +/-10m error might therefore be expected in the positioning of the ground truth sample. Overall positional error for the *RoxAnn* surveys is therefore in the range of +/- 30m. In heterogeneous seabed areas this might have lead to habitat misclassification and may partially explain the overlap in the habitat signatures used in the *RoxAnn* supervised classification process.

9.3. THE INFLUENCE OF INTERPOLATION

If the *RoxAnn* tracks are close together the interpolation process is a fairly robust process, however where the tracks are far apart, interpolation may introduce significant inaccuracies into the resulting map [67]. The track spacing could be used as an indication of the descriptive resolution of the resulting map. If the seabed habitats are considered to be extremely fragmented and heterogeneous, an accurate map with complete coverage using *RoxAnn* could only be created if the sonic footprints of the echosounder overlap. This equates to a track spacing of around 7m using the echosounder setup for this survey. In the time available for the survey there was little opportunity for such intensive tracking.

With widely spaced tracks the resulting map accuracy is affected however, map accuracy is not directly related to the track spacing as it also depends on the habitat patch size and the degree of heterogeneity of the habitats. In this survey it is assumed that the habitats are often homogeneous between the tracks. This assumption will have undoubtedly introduced inaccuracies into the resulting map but examination of the track data (maps 3 + 4 section B) reveals that in some areas tracking is more intensive than in others and these intensively tracked areas are therefore likely be more accurate. Tracking over areas with variable depth and high E1 and E2 values (assumed to be coral reefs) was intentionally intensified on the northern side of Great Corn Island because local knowledge and previous reef surveys [60] revealed that coral reefs existed in heterogeneous patches here. This intensive tracking would have been repeated in areas to the North East of Little Corn Island but limited time and resources and bad weather at the time of the survey restricted access. The classification for offshore reefs on Little Corn Island should therefore be treated with a degree of caution as further surveys are undoubtedly required to improve the accuracy of the map in this area.

9.4. LIMITATIONS OF LANDSAT:

The most significant limitation of the Landsat classification was the gap between the date of capture and the ground truthing survey. As previously outlined this was likely the cause of spectral confusion in the initial supervised classification attempt. Attempts to rectify this problem by deleting training site data that conflicted with a visual interpretation of the satellite image will have introduced errors in the Landsat classifications. Habitat change is also only one cause of problems in the supervised classification process. Depth invariant image processing was not possible because of variation in turbidity around the islands at the time of capture. Although only shallow areas were included in the classification it is likely those areas in deeper water (8-12m range) may have been misclassified, and in areas of higher turbidity this misclassification would be accentuated. The band of rubble, algae & seafan habitat edging the Great Corn Island classification was probably a result of this depth influence, however as previously outlined, the *RoxAnn* classification took precedent in overlapping areas assuming a higher confidence in the ability of *RoxAnn* to classify these areas given the required editing of the Landsat data.

The spatial resolution of Landsat ($30m^2$) is relatively low in comparison to other satellite sensors (e.g.: Ikonos, Quickbird & SPOT) and this may influence the accuracy of the classification. Each pixel in the image is assumed to be a homogenous area, but in reality there are likely to be a number of mixed habitat pixels or 'mixels' which will each have a spectral reflectance somewhere in between the reflectance of that habitats that make up that pixel. This results in a degree of misclassification during the supervised classification process [74].

Positioning error also has the potential to cause significant inaccuracies in satellite classification. The satellite image was geometrically corrected prior to acquisition but georeferencing of the image was undertaken using GPS points from around the coastline of each of the Islands. It was not possible to gather points from the edges of the image however and this might have resulted in a degree of warping in the image (especially towards the edges). Additionally, GPS positional inaccuracies of +/- 5m were also a source of error in the georeferencing process. A further positional error of around +/- 5-10m could be expected during the ground truth surveys. Training sites were selected based on the homogeneity of the surrounding habitat to try to avoid the problem of misclassification but given a cumulative error of +/-15m is quite possible that some training site pixels were misclassified. However, most of these misclassified pixels were likely deleted during the process of signature rectification (section 7.2.3).

9.5. LIMITATIONS OF THE CLASSIFICATION SCHEME

A recent study found that *RoxAnn* AGDS can achieve an intermediate descriptive resolution map (5 classes) with map accuracies comparable to those from Landsat TM [69]. This study utilised a hierarchical classification scheme similar to that devised by Mumby and Harbourne for Belize [73]. However, neither of these classification schemes incorporates a specific measure of rugosity that might be more appropriate to the classification of *RoxAnn* data and this likely resulted in a higher degree of signature overlap and confusion than is possible with *RoxAnn*. In an attempt to rectify this for this study it was hoped that adapting the scheme from Belize to include habitats with differing rugosities (rubble & algae, sand & algae, and rubble, algae & seafans) might improve the classification ability of *RoxAnn* and help to avoid the problem of signature overlap that would be expected from merging these classes as bare substratum as outlined in the original classification scheme [73]. As observed in the signature analysis (figure 4) this was only partially successful and there was still overlap between these component classes and the Sand and Seagrass classes however this overlap may also be a result in positional inaccuracies in the ground truth data. The dissection of the bare substratum class was certainly justified and the development of a hierarchical classification scheme incorporating a measure of rugosity is recommended for any future *RoxAnn* surveys. Although acoustically dissimilar, the spectral similarity of these component habitats resulted in problems with the Landsat classification on Great Corn and subsequent confusion between the sand & algae (SA) and rubble algae (RA) habitats.

9.6. PROBLEMS WITH COMBINING ACOUSTIC AND OPTICAL METHODS:

Optical remote sensing is clearly able to discriminate between certain habitats better than AGDS and vice versa. This reveals a fundamental problem with trying to combine acoustic and optical data. The resulting combined map will likely have a high degree of misclassification between the RA and SA habitats in shallow water (produced by Landsat) and misclassification of S & SA, and RA & RAS in deeper water (produced by *RoxAnn*). However, both methods were significantly better at discriminating coral reefs which was the principle aim of the study and it is also hoped that the use of contextual editing improved the classification of RAS and SE habitats.

9.7. NEED FOR AN ACCURACY ASSESSMENT:

Time and resource limitations meant that it was not possible to carry out an accuracy assessment on the final maps. Previous studies have achieved an accuracy of around 50% for both Landsat and *RoxAnn* at medium descriptive resolution [69, 81]. However accuracy will vary widely with *RoxAnn* depending on the track spacing and the problems in processing the Landsat imagery will have reduced the accuracy. An accuracy assessment is therefore essential before the maps are used for any management or policy applications. Details on how to carry out an accuracy assessment can be found in *The Remote Sensing Handbook for Tropical Coastal Management* [74].

10.CONCLUSION

This study has successfully provided supervised classifications of the marine habitats surrounding the Corn Islands to several Nicaraguan Government institutions and local universities. Applications of these maps are discussed further in the following appendix outlining the value, threats and management recommendations for each of the habitats classified in the maps and include:

- information to support coastal resource management and planning,
- information to support fisheries management based on essential fisheries habitats,
- identification of the distribution of important, biodiverse and fragile habitats,
- support in the design of any marine park or protected area,
- resources for use in environmental education and awareness,
- a marine basemap for a Corn Islands coastal geographic information system

The construction of a local geographic information system (GIS) combining this data is highly recommended and this would provide a baseline for monitoring human and natural impacts to the islands' marine resources as well as providing localised scientific studies to support fisheries and marine resource management measures. In addition developing a GIS resource which integrated this data with existing studies from central government and regional NGO's as a data sharing activity might help to promote integration in coastal management and planning both horizontally, between sectors of government, the community, NGO's and Universities, and vertically, between different levels of government as part of the continuing decentralisation process.

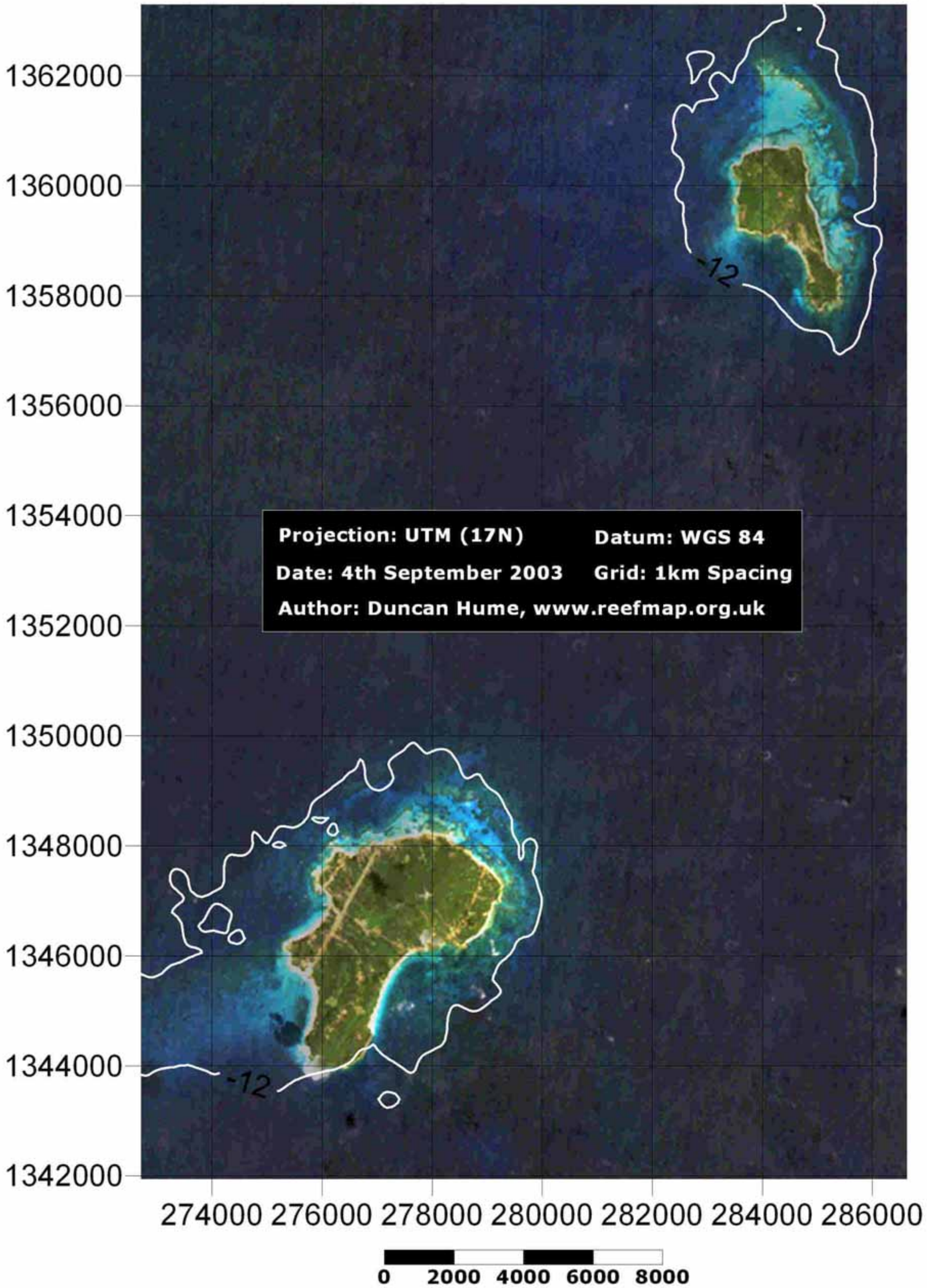
This study also demonstrates the capabilities of *RoxAnn* and Landsat and outlines some of the limitations of combining satellite and acoustic classifications. The total cost of undertaking the *RoxAnn* survey is estimated at around £7500 which is more expensive than using satellite imagery for the same spatial coverage [82]. However, as was demonstrated in this study, satellite imagery has serious limitations in turbid waters and still requires a field survey for supervised classification. *RoxAnn* provides an alternative that provides data in a suitable format for image processing in a short time scale.

11.ACKNOWLEDGEMENTS

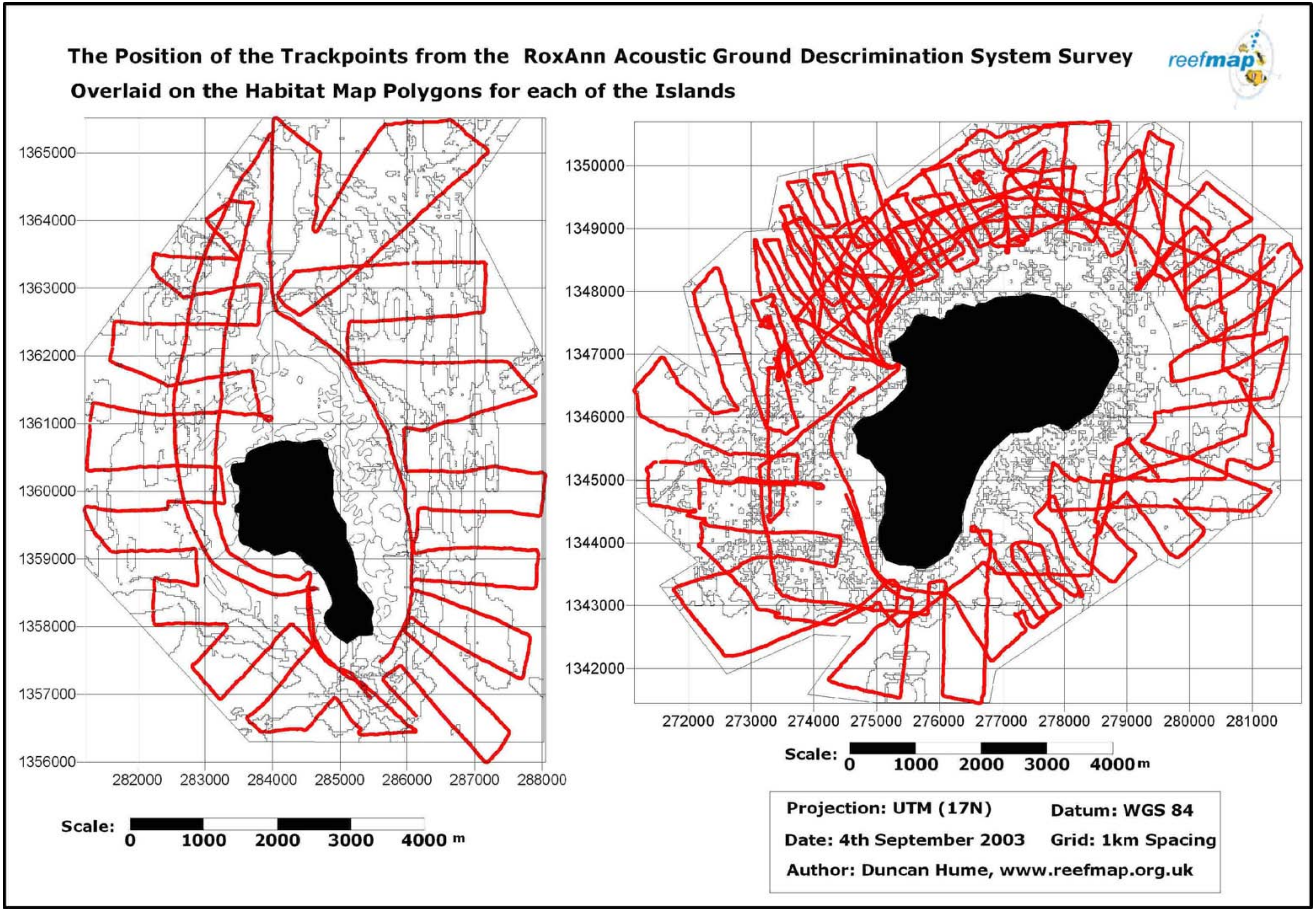
This research was supported by the Natural Environment Research Council, The Royal Geographical Society with the Institute of British Geographers, The University of Newcastle Exploration Society, The Rufford Foundation, PADI Project Aware, Coral Cay Conservation, The Gilchrist Educational Trust, Brooksbank Valves Ltd, P&O, RAAS-Asdi-RAAN, Dive Little Corn and Casa Iguana. I offer my greatest thanks to Joe Ryan for his support and invaluable information relating to the reefs of the Corn Islands and for his encouragement in organising this study and to Norma Dixon, Amanda Proctor and Marcos and Janet Gomez for their help in and support during the field studies. I would also like to thank Dr. Robert Foster-Smith for all his advice guidance and support throughout and to the staff at Envision in Newcastle for the generous contribution of time, equipment and resources to the surveys. I am would also like to acknowledge the support of Dr Ed Green at UNEP-WCMC for the contribution of the Landsat imagery, Kristian Teleki ICRAN for advice and contacts in Central America and Dr. A. Edwards for advice and help on satellite image processing. Thanks also to Major Peter Ormerod and Dr. Rob Nunny for their support in the planning stages of the project.

CHAPTER 2: SECTION B: MARINE HABITAT MAPS

Landsat TM Image of the Corn Islands overlaid with a 12m Depth Contour (Generated from AGDS Survey) Demonstrating the Limit of Light Penetration around the Islands

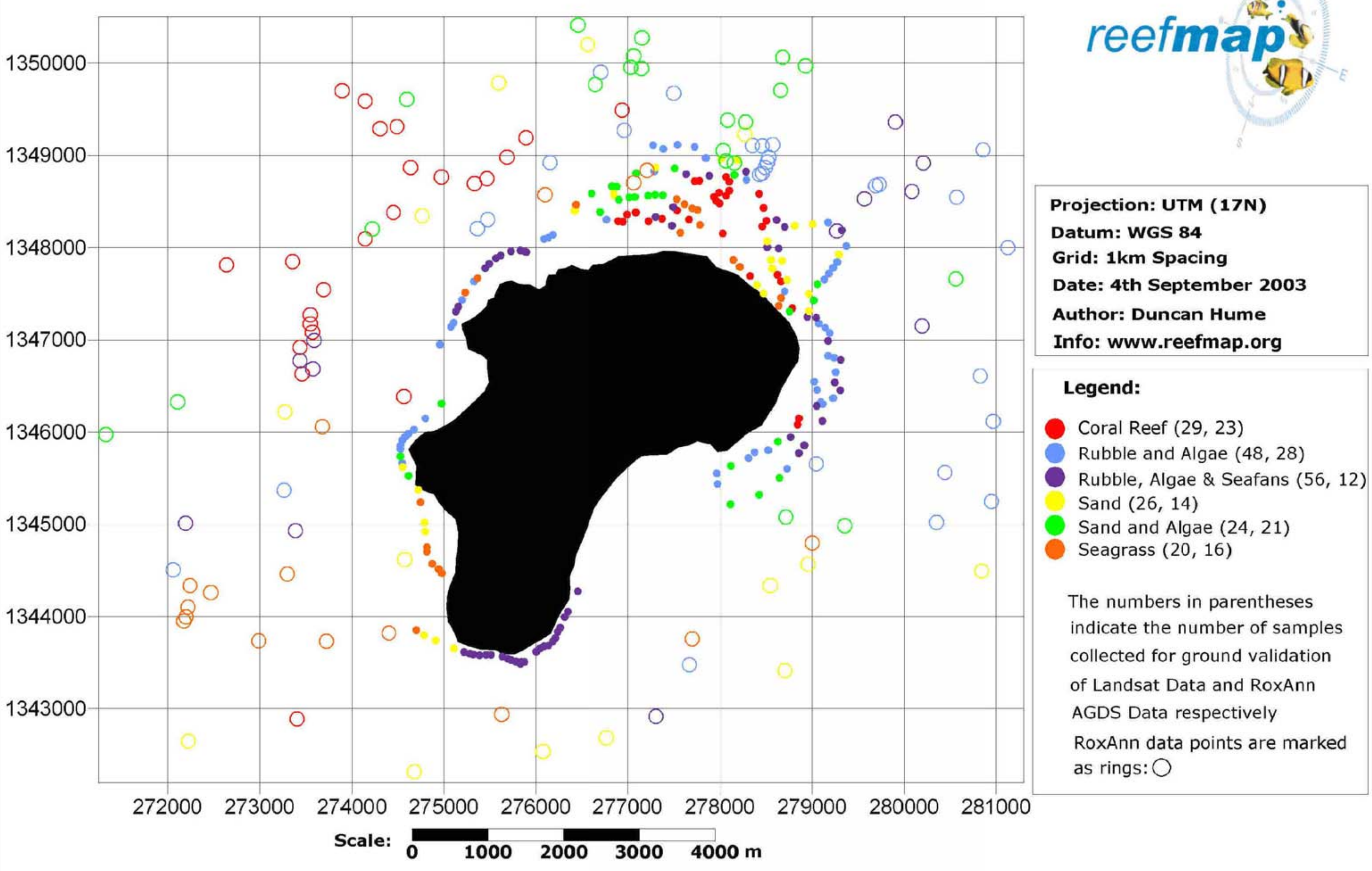


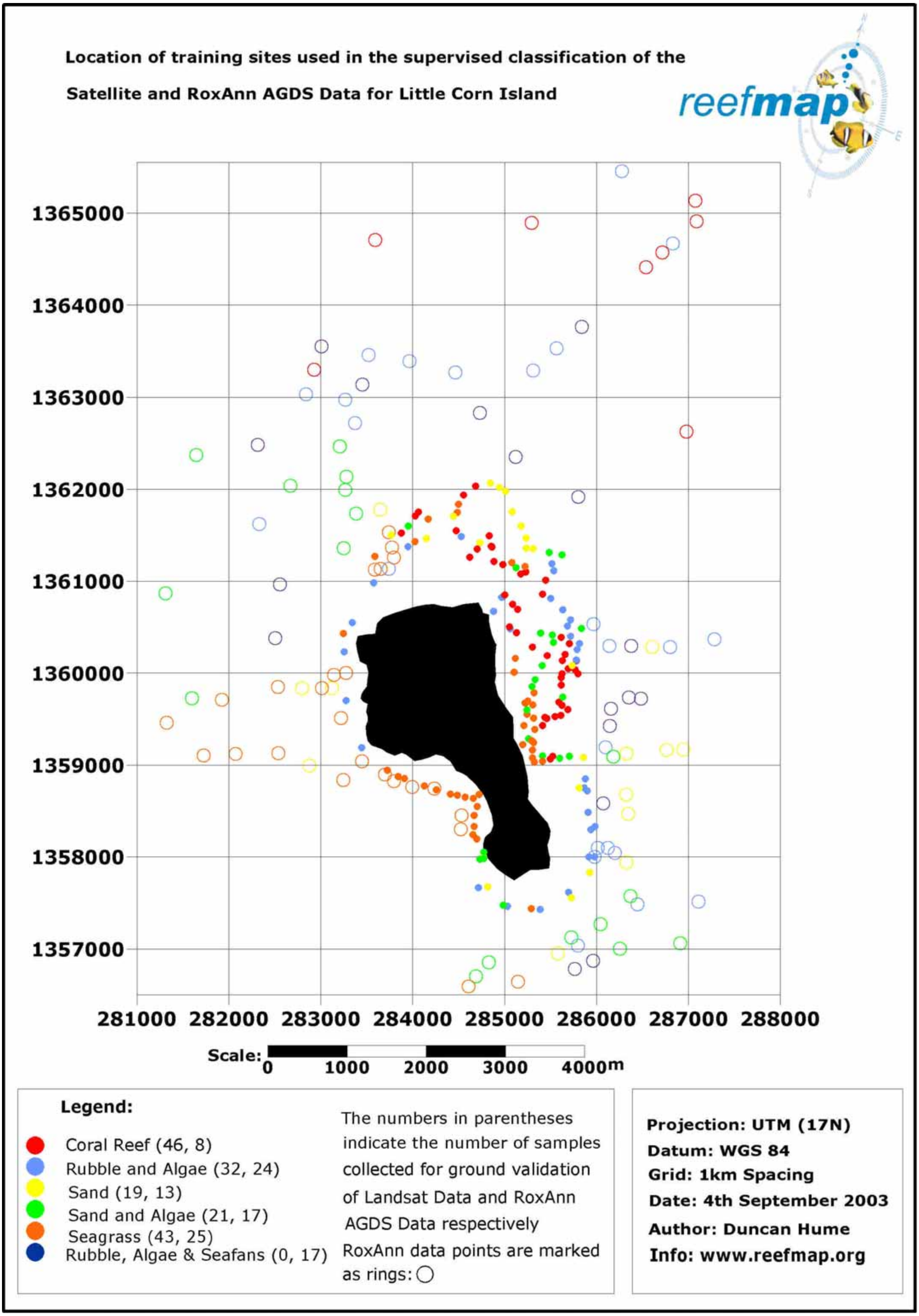
Note:Landsat TM Imagery contributed by The World Conservation Monitoring Centre (Cambridge)



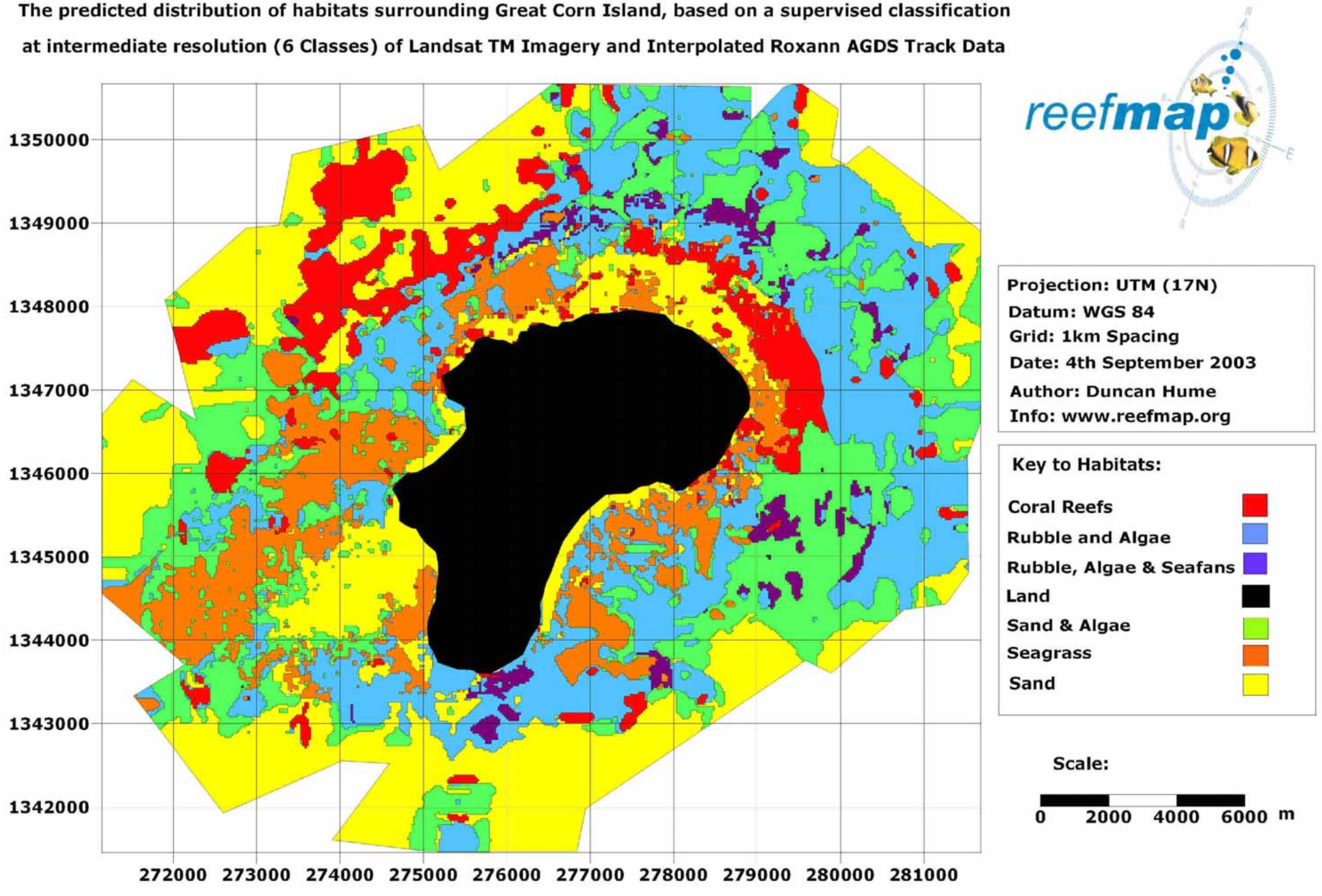
The Position of the Trackpoints from the RoxAnn Acoustic Ground Descrimination System Survey
Overlaid on the Habitat Map Polygons for each of the Islands
reefmap
1365000
1364000
1363000
1362000
1361000
1360000
1359000
1358000
1357000
1356000
282000 283000 284000 285000 286000 287000 288000
Scale: 0 1000 2000 3000 4000 m
1350000
1349000
1348000
1347000
1346000
1345000
1344000
1343000
1342000
272000 273000 274000 275000 276000 277000 278000 279000 280000 281000
Scale: 0 1000 2000 3000 4000 m
Projection: UTM (17N)
Datum: WGS 84
Date: 4th September 2003
Grid: 1km Spacing
Author: Duncan Hume, www.reefmap.org.uk

Location of training sites used in the supervised classification of the Satellite and RoxAnn AGDS Data

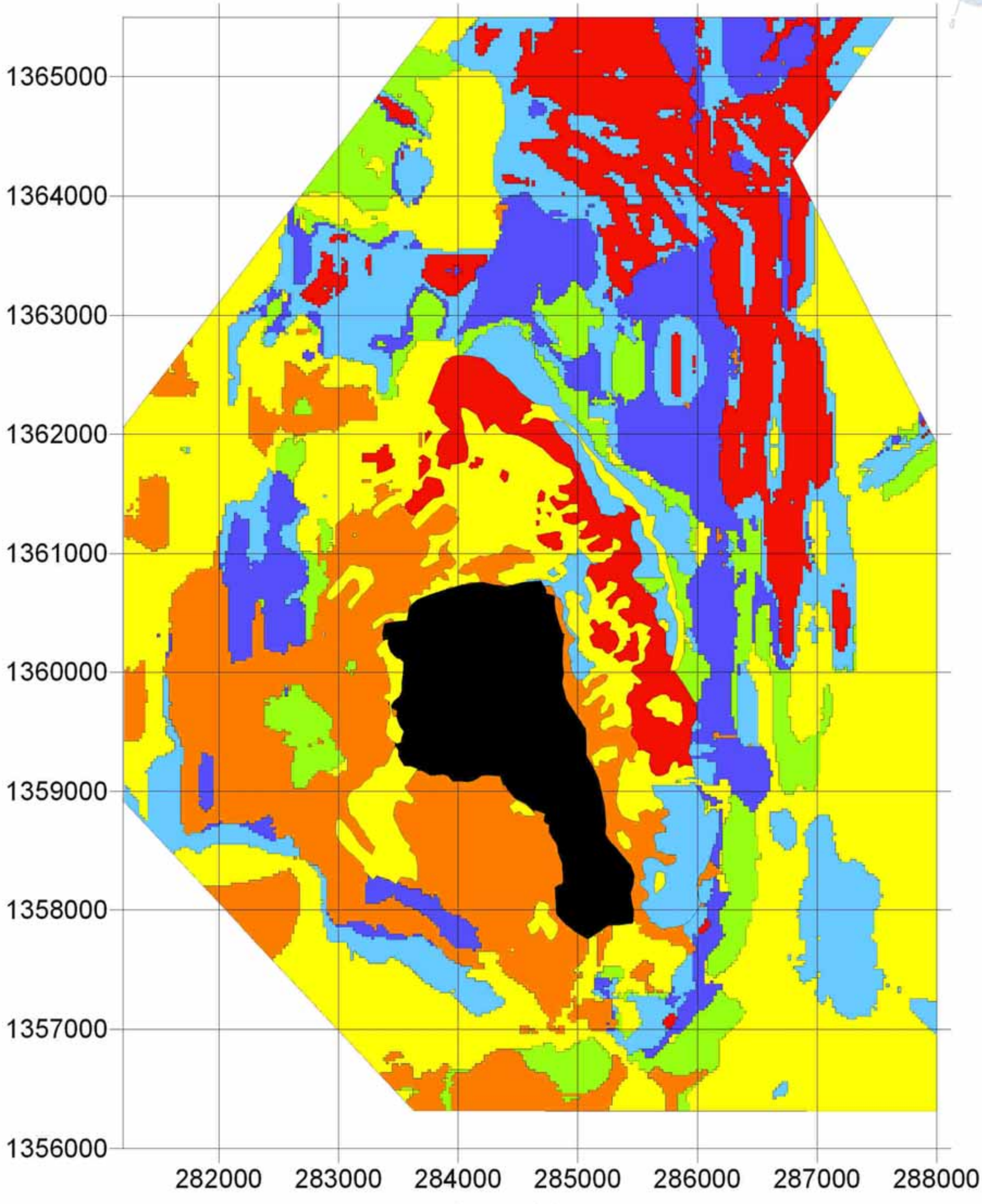



Location of training sites used in the supervised classification of the
Satellite and RoxAnn AGDS Data for Little Corn Island
reefmap
1365000
1364000
1363000
1362000
1361000
1360000
1359000
1358000
1357000
281000 282000 283000 284000 285000 286000 287000 288000
Scale: 0 1000 2000 3000 4000m
Legend:
Coral Reef (46, 8)
Rubble and Algae (32, 24)
Sand (19, 13)
Sand and Algae (21, 17)
Seagrass (43, 25)
Rubble, Algae & Seafans (0, 17)
The numbers in parentheses indicate the number of samples collected for ground validation of Landsat Data and RoxAnn AGDS Data respectively
RoxAnn data points are marked as rings:
Projection: UTM (17N)
Datum: WGS 84
Grid: 1km Spacing
Date: 4th September 2003
Author: Duncan Hume
Info: www.reefmap.org

The predicted distribution of habitats surrounding Great Corn Island, based on a supervised classification at intermediate resolution (6 Classes) of Landsat TM Imagery and Interpolated Roxann AGDS Track Data



The predicted distribution of habitats surrounding Little Corn Island, based on a supervised classification at intermediate resolution of Landsat TM Imagery and Interpolated Roxann AGDS Track Data



Note: not to be used for navigation

Scale: 0 1000 2000 3000 4000 m

Projection: UTM (17N) **Datum: WGS 84**

Date: 4th September 2003 **Grid: 1km Spacing**

Author: Duncan Hume, www.reefmap.org.uk

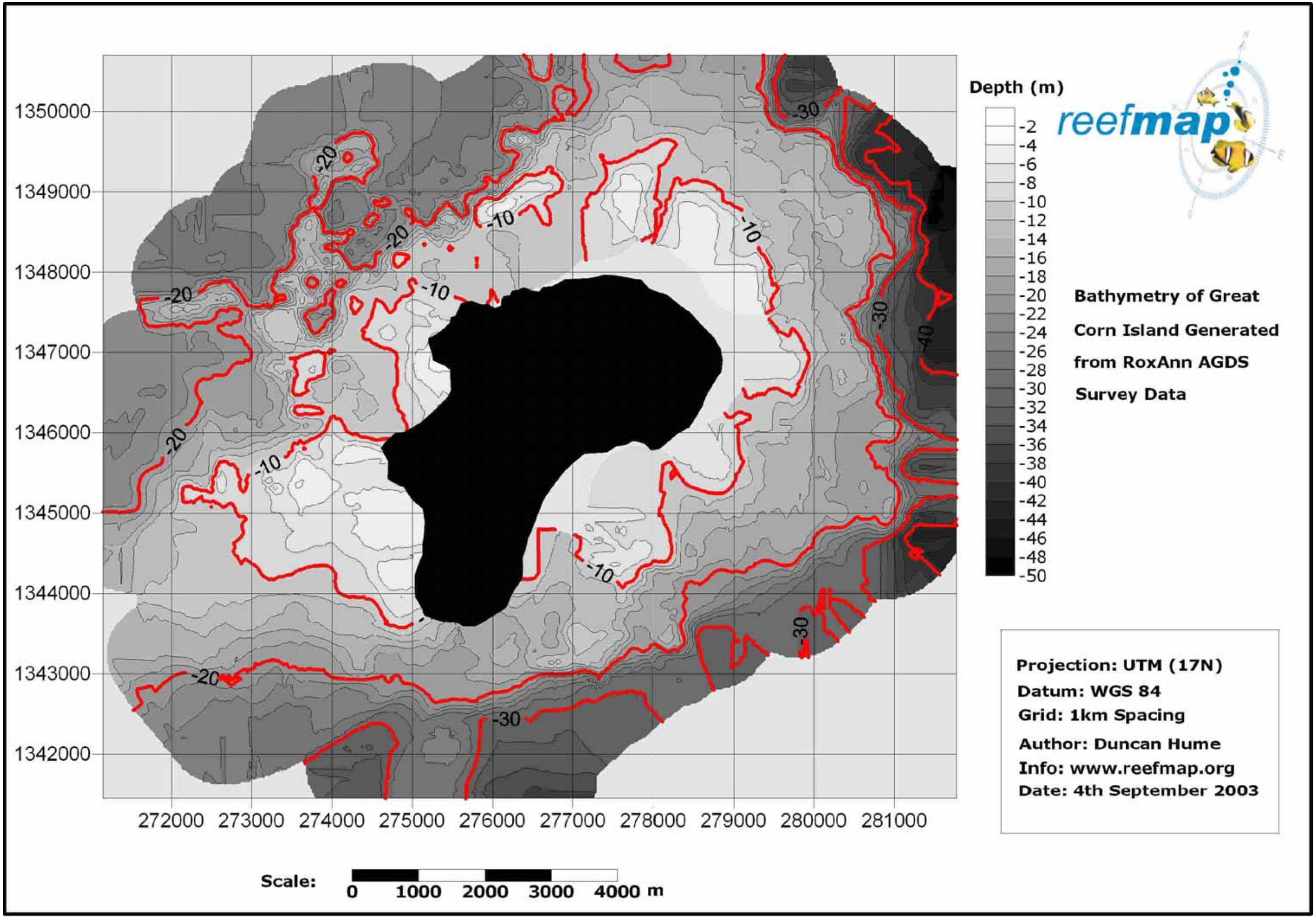
Key to Habitats:

Land

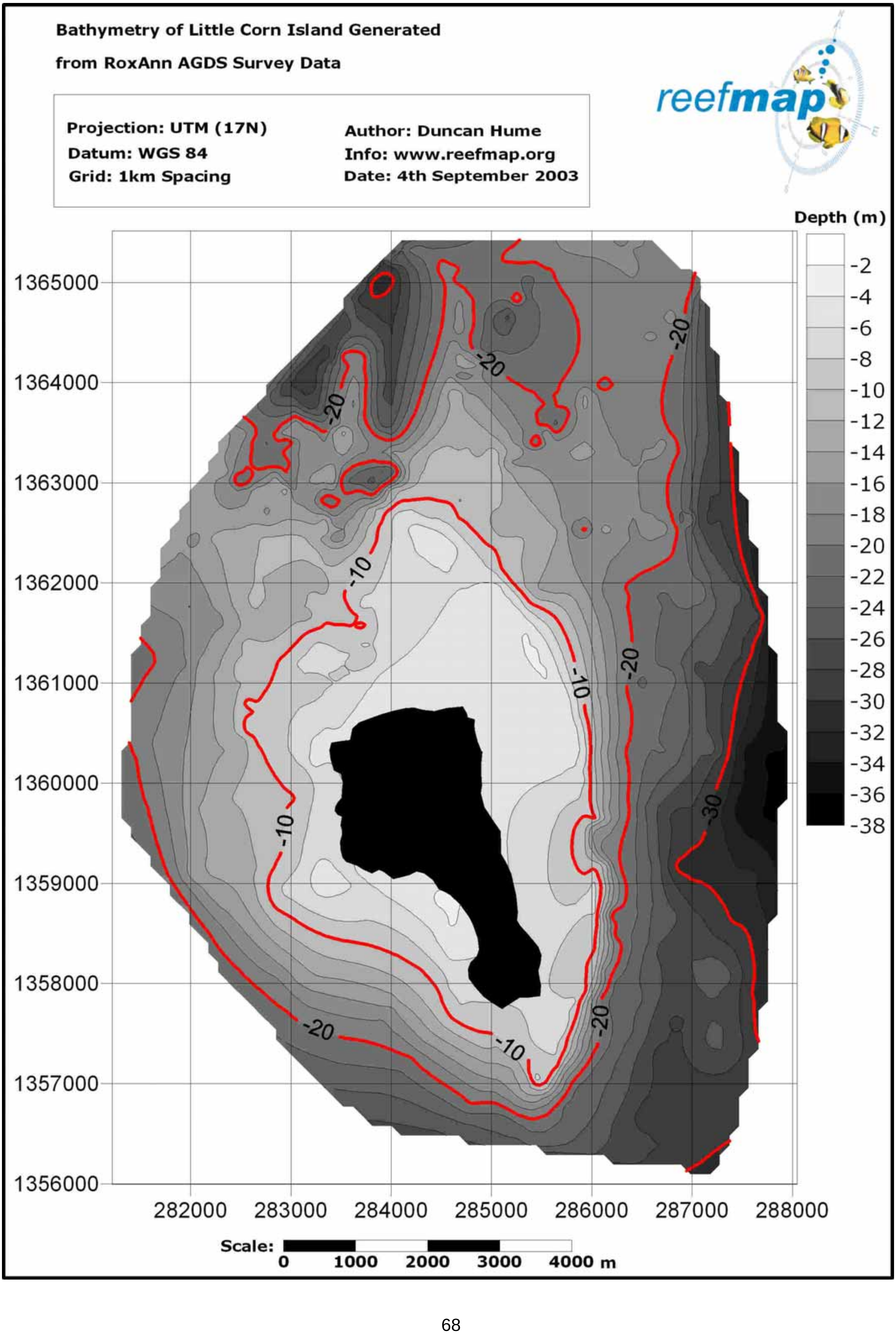
Coral Reefs **Sand & Algae**

Rubble and Algae **Seagrass**

Rubble, Algae & Seafans **Sand**



Depth (m)
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
-32
-34
-36
-38
-40
-42
-44
-46
-48
-50
reefmap
Bathymetry of Great Corn Island Generated from RoxAnn AGDS Survey Data
Projection: UTM (17N)
Datum: WGS 84
Grid: 1km Spacing
Author: Duncan Hume
Info: www.reefmap.org
Date: 4th September 2003
1350000
1349000
1348000
1347000
1346000
1345000
1344000
1343000
1342000
272000
273000
274000
275000
276000
277000
278000
279000
280000
281000
Scale:
0
1000
2000
3000
4000 m
-10
-20
-30
-40



Bathymetry of Little Corn Island Generated
from RoxAnn AGDS Survey Data
Projection: UTM (17N)
Datum: WGS 84
Grid: 1km Spacing
Author: Duncan Hume
Info: www.reefmap.org
Date: 4th September 2003
reefmap
Depth (m)
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
-32
-34
-36
-38
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1364000
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1359000
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1356000
282000
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284000
285000
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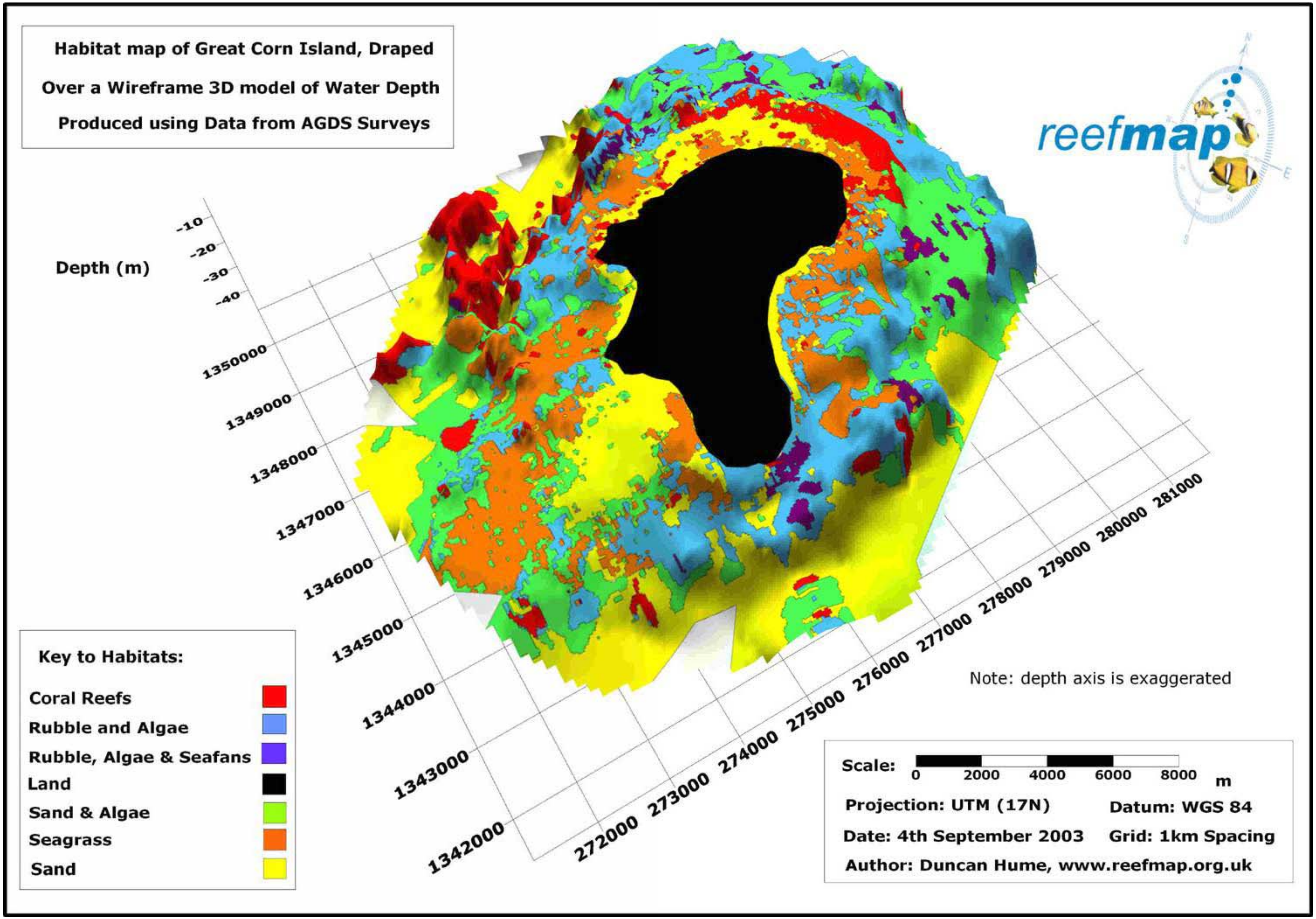
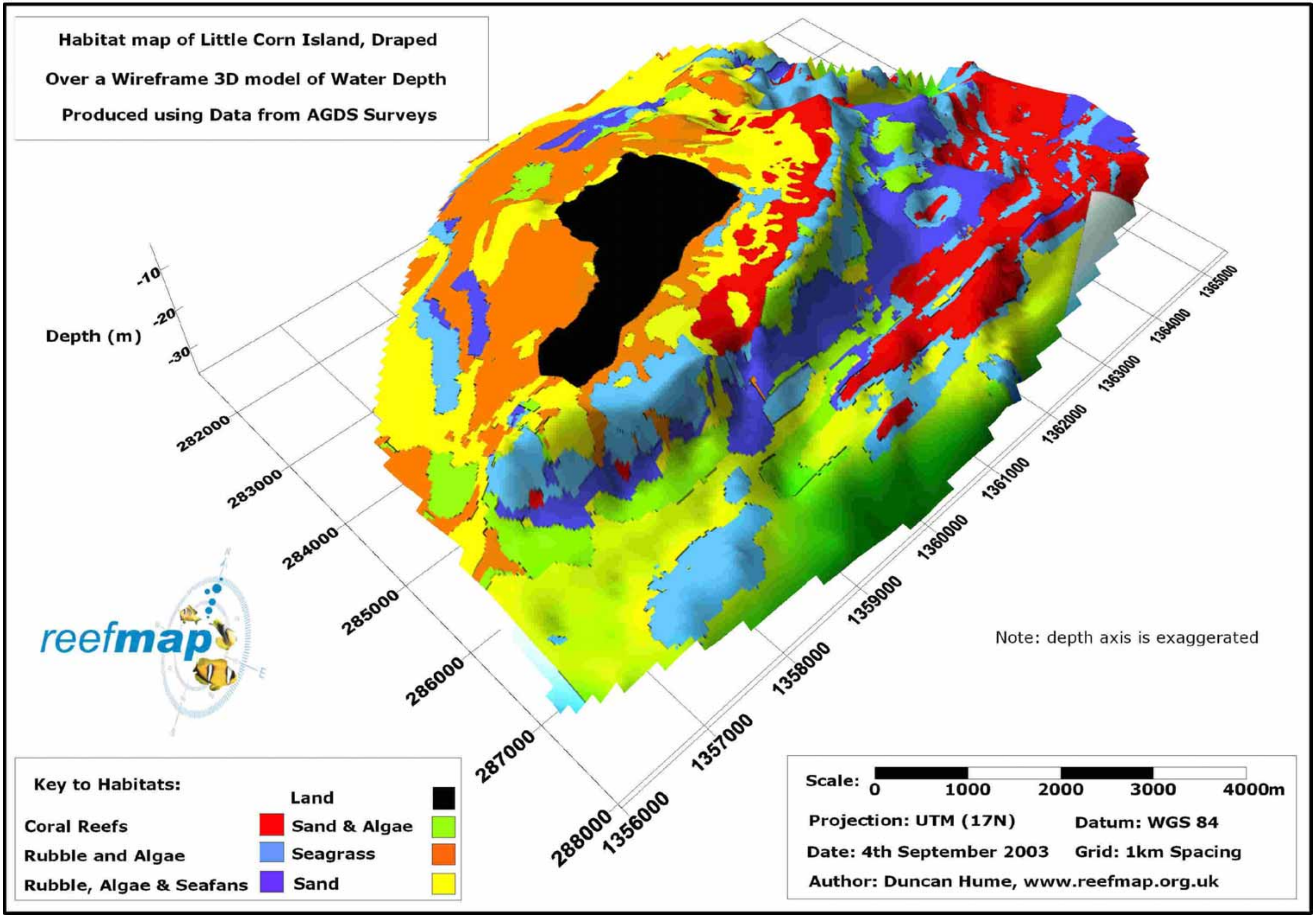
287000
288000
-20
-10
-30
Scale:
0
1000
2000
3000
4000 m



Habitat map of Great Corn Island, Draped
Over a Wireframe 3D model of Water Depth
Produced using Data from AGDS Surveys
reefmap
Depth (m)
-10
-20
-30
-40
1350000
1349000
1348000
1347000
1346000
1345000
1344000
1343000
1342000
272000 273000 274000 275000 276000 277000 278000 279000 280000 281000
Note: depth axis is exaggerated
Key to Habitats:
Coral Reefs
Rubble and Algae
Rubble, Algae & Seafans
Land
Sand & Algae
Seagrass
Sand
Scale: 0 2000 4000 6000 8000 m
Projection: UTM (17N)
Datum: WGS 84
Date: 4th September 2003
Grid: 1km Spacing
Author: Duncan Hume, www.reefmap.org.uk


Habitat map of Little Corn Island, Draped
Over a Wireframe 3D model of Water Depth
Produced using Data from AGDS Surveys
Depth (m)
-10
-20
-30
282000
283000
284000
285000
286000
287000
288000
1356000
1357000
1358000
1359000
1360000
1361000
1362000
1363000
1364000
1365000
Note: depth axis is exaggerated
reefmap
Key to Habitats:
Coral Reefs
Rubble and Algae
Rubble, Algae & Seafans
Land
Sand & Algae
Seagrass
Sand
Scale: 0 1000 2000 3000 4000m
Projection: UTM (17N)
Datum: WGS 84
Date: 4th September 2003
Grid: 1km Spacing
Author: Duncan Hume, www.reefmap.org.uk

CHAPTER 2: SECTION C: COASTAL AND MARINE HABITAT ASSESSMENTS

A rapid assessment of the coral reef community structure and health of the Corn Islands using the AGRRA protocol

Author: Alex Hunt, alex@reefmap.org.uk

ABSTRACT:

The coral reef habitats surrounding the Corn Islands of Nicaragua appear to be under threat from increasing human impacts as a result of rapid coastal development. In response to this apparent habitat degradation the government intends to implement an ICM plan for the islands. However, up-to-date information on the community structure and condition of the reefs is lacking. With the application of a standardised regional protocol for surveying reef health, a program of surveys was conducted on the two islands in order to provide the municipality with information for the formulation of an effective management scheme. Local involvement in the project was sought to aid in capacity building and community involvement culminating in a stakeholder workshop. Variability in reef condition between sites was high according to numerous indicators of health. Shallow sites were found to be in a poor condition with low cover of live coral and low levels of coral recruitment. Deeper reefs dominated by *Montastraea annularis* appeared in a better state with high percent live coral cover and recruitment for the region and relatively well developed community structure. However, the proportion of *M. annularis* colonies affected by white plague disease was particularly high at some of the deeper sites and there are indications of an imbalance in the herbivory process with frequent observations of algal overgrowth.

CHAPTER 2: SECTION C: COASTAL AND MARINE HABITAT ASSESSMENTS

A rapid assessment of the coral reef community structure and health of the Corn Islands using the AGRRA protocol

Author: Alex Hunt, alex@reefmap.org.uk

ABSTRACT:

The coral reef habitats surrounding the Corn Islands of Nicaragua appear to be under threat from increasing human impacts as a result of rapid coastal development. In response to this apparent habitat degradation the government intends to implement an ICM plan for the islands. However, up-to-date information on the community structure and condition of the reefs is lacking. With the application of a standardised regional protocol for surveying reef health, a program of surveys was conducted on the two islands in order to provide the municipality with information for the formulation of an effective management scheme. Local involvement in the project was sought to aid in capacity building and community involvement culminating in a stakeholder workshop. Variability in reef condition between sites was high according to numerous indicators of health. Shallow sites were found to be in a poor condition with low cover of live coral and low levels of coral recruitment. Deeper reefs dominated by Montastraea annularis appeared in a better state with high percent live coral cover and recruitment for the region and relatively well developed community structure. However, the proportion of M. annularis colonies affected by white plague disease was particularly high at some of the deeper sites and there are indications of an imbalance in the herbivory process with frequent observations of algal overgrowth.

1. INTRODUCTION

It has been suggested that a regional program needs to be developed to better identify, characterise, and monitor the extent and condition of coral reef habitat in Central America [83]. Presently, there is a general lack of available information on the status of Central American coral reefs, with notable exceptions including Yucatan Mexico, the Belize barrier reef system and the Bay Islands of Honduras [83].

The recent launch of the World Bank-funded Mesoamerican Barrier Reef System (MBRS) project represents a promising step towards the development of integrated coastal management (ICM) initiatives in the region. The project has the potential to provide much-needed information on the coastal habitats of Mexico, Belize, Guatemala and Honduras [84]. However, in order that effective management plans can incorporate the entire region it is essential that surveying and monitoring is extended to cover less known areas and countries not assisted by this program.

The state of the extensive, yet sparsely-studied reefs and coral communities on the Caribbean shelf of Nicaragua is of particular concern as a result of rapidly increasing coastal development [63]. The Corn Islands are particularly vulnerable since they represent the most heavily populated area on the entire Atlantic coast [85]. A thriving lobster fishing industry and increasing tourism have attracted immigration from the mainland to these two small islands and limited research carried out on the coral reefs suggests that in many cases these habitats have undergone significant degradation as a result of unsustainable land use, expanding tourism, industrial development, over-fishing, pollution from poor sewage treatment and waste disposal [63, 85, 86].

In order to address the issue of human impacts on the natural resources of the Corn Islands, the Ministry of the Environment and Natural Resources (MARENA) has identified six areas of primary environmental concern which include the health of the coral reefs of the municipality [87]. In response to the evidence of coastal habitat degradation around the islands, MARENA have drawn up an action plan which includes the establishment of a marine park with the main objective of conserving these resources [88]. However, although some surveys have occurred previously at sites on the larger of the two islands [60, 63, 85, 89], there is a paucity of up-to-date information on the overall extent, spatial variability in community structure and the health of the coral reefs, so effective siting and zonation of a marine park would be unlikely based on existing knowledge.

A program of surveys designed to provide baseline data on the community structure and health of coral reefs could help to fill in existing knowledge gaps and act as an essential component in the toolbox of the decision-makers when formulating such plans for the future of these relatively undeveloped Caribbean islands. In addition, the application of a standardised methodology specifically designed for application to the coral reefs of the area facilitates comparisons with other sites on a more regional scale. The protocol set by the Atlantic and Gulf Rapid Reef Assessment (AGRRA) organisation has been used at numerous sites throughout the wider Caribbean region since 1997 and is the first and only program that has developed an extensive regional database on Caribbean coral reef condition [90].

The AGRRA methodology focuses upon reef health using a number of structurally or functionally important benthic indicators such as coral size-frequency distributions, percent mortality and presence of disease to give a broad overview of reef condition. In addition, a major component of the AGRRA program is the standardisation of the protocol through training of individuals in the assessment methodology and in observation consistency through calibration thus improving the comparability of data collected by different individuals at various locations in the region.

By applying the AGRRA protocol to selected sites on the reefs of the Corn Islands I aimed to fulfil two main objectives: (1) to provide the municipality of the Corn Islands with baseline information on the condition of the coral reefs for use in management decision-making; and (2) to offer the first records from Nicaragua for the AGRRA regional database currently under development.

2. MATERIALS AND METHODS

2.1. SITE DESCRIPTION

Nicaraguan coral reefs vary from small patches and pinnacles (tens of meters in diameter) to large complicated platforms (kilometres wide) and well-defined belts [63]. This network of reefs has been divided into six major areas, and the Corn Islands form two of these major sites of coral reef growth [91]. The islands are volcanic in origin and are situated 68 km from the mainland. The largest of the two islands, Great Corn, has a population of over 6500 and is just 5km long from the North to the South, covering an area of 10.3km^2 [85]. Little Corn Island is located 15 km to the northeast of Great Corn and is just one half the size with around a tenth of the population. Sections of the fringing reef of Great Corn Island were qualitatively described by Geister [92] and Roberts & Suhayda [61] before being devastated by Hurricane Joan in 1988 [85]. The windward northwest and northern shore of the island has a complex and discontinuous triple fringing reef structure [92] which generally reaches depths of between 15-20 m before giving way to extensive sand flats. The windward fringing reef on the north eastern side of Little Corn has a very different structure. It is continuous and shallow, seldom reaching depths below 10 m before giving way to sand. There are numerous small patch reefs located within the sheltered lagoon leeward of the main fringing reef. Coral growth elsewhere around the island is minimal.

2.2. SURVEY TRAINING

The survey team of six comprised of local university students and regional coral reef scientists in addition to the author. Before surveys commenced, a 14 day workshop was held on Little Corn Island in order to familiarise the team with field identification skills and the survey methodology. A series of standardisation procedures were conducted in order to reduce observer bias and ensure that the data will be comparable to other AGRRA sites in the region: divers would record information following the AGRRA protocol from the same transect and results were compared over two days. Surveys commenced once the relative disparity in observation between surveyors was less than 10%.

2.3. SAMPLE SITE SELECTION

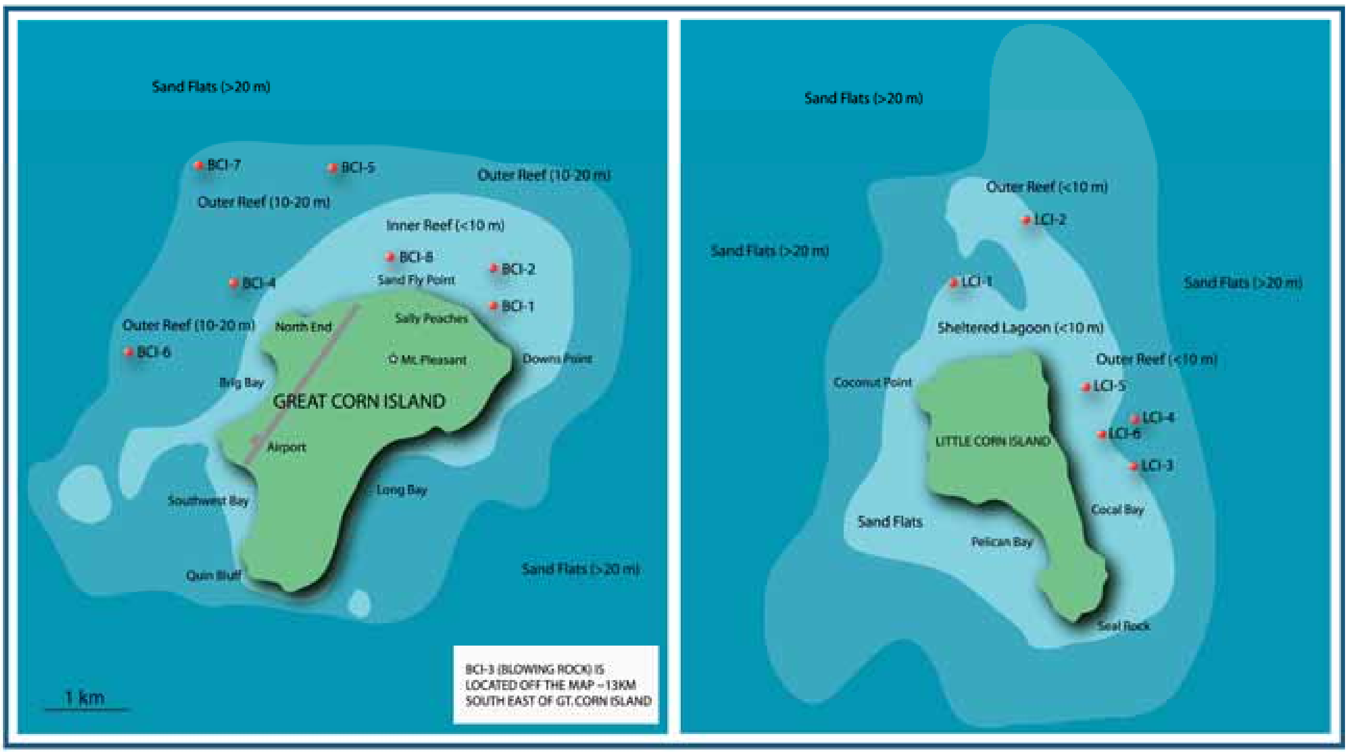


Figure 1. Location of the 14 AGGRA survey sites.

The team conducted surveys of eight sites around Great Corn Island following the AGRRA protocol [90]. A combination of satellite imagery (Landsat 5 TM), information from previous studies [60, 63, 85, 89], nautical charts [62], manta tows, local knowledge and preliminary roughness and hardness data from a seabed mapping study of the islands using an acoustic ground discrimination system (AGDS) was used to select appropriate sites which were representative of the type of reef habitats found in the area. The locations of the sites which were selected are shown in Fig. 1. Reef development below depths of around 10 m is extremely patchy due to a lack of suitable substrate at Little Corn. Therefore, five out of the six sites on the windward fringing reef (LCI 2-6) were located within the shallow '*Acropora palmata*' zone at a depth where coral growth was maximal (mean sample depth = 5.37 m), and one was situated in the north east (LCI 2) and the remainder on the eastern side of the island (LCI 3-6). These sites were characterised by relatively low coral cover and diversity and were generally dominated by *Porites astreoides*. Site LCI 1 represents a relatively unique habitat around the island, since there are very few well-developed areas of reef that are sheltered from wave action. The site was located on a large, shallow reef patch (mean sample depth = 6.53 m) in the lagoonal area leeward of the main fringing reef. LCI 1 was dominated by *Montastraea annularis* and exhibited relatively high coral cover.

In accordance with AGRRA protocol, sites at Great Corn Island were located within the two distinct depth ranges of maximal coral growth (1-5 m and 10-15 m). Three sites (BCI 1, 2 and 8) were situated within the shallow inner fringing reef zone on the north-eastern side of the island (mean sample depth = 3.88 m. These sites follow the same general description as the shallow sites at Little Corn. However, BCI 3 represents a unique habitat for the islands. The site was located at Blowing Rock, an exposed basaltic outcrop covered with a dense coral community located roughly 13 km southwest of Great Corn. Surveys were conducted at a mean depth of 13.08 m where coral growth was maximal. The remaining sites (BCI 4-7) were situated on the deep outer fringing reef (mean sample depth = 12.59 m) on the north-western side of the island where coral cover and diversity was relatively high and the reefs were generally dominated by *M. annularis*.

2.4. DATA COLLECTION

The cover of live scleractinian coral, algae, sponges, gorgonians, sand and bare rock was recorded for a minimum of 6 (10 m) transects per site, with a total of 124 surveyed overall (Fig. 2). The measurements were recorded as number of centimetres per transect per class and subsequently converted to percentages, e.g. % live coral = 100 (live coral cover in cm / length of transect in cm). All scleractinian corals greater than 10 cm intersected by the transect line were identified to species. Observations were also made of several reef health parameters: (1) maximum colony diameter and height; (2) estimates for percent 'recent' and 'old' partial mortality, as defined by presence or absence of visible corallite structure respectively (NB: notable exceptions to this rule include parrotfish bites where corallite structure has often been removed, but which are often considered to be recent mortality; and overgrowth by other organisms such as boring sponges of the genus *Cliona*, which is considered to be 'old' mortality even though corallites are often visible); (3) presence and identification of disease; (4) presence of partial or total bleaching; (5) and presence of other identifiable impacts Following AGRRA protocol these parameters were recorded for dead colonies which can be identified to species level. Observations were made for a minimum of 50 coral heads per site, with a total of 2079 investigated overall.

Figure 2. A diver surveys an AGRRA benthic transect on a shallow reef at Little Corn Island.

To examine the algal community, a 25 cm^2 quadrat was used to sample points 1, 3, 5, 7 and 9 m along the transect within areas where algal cover is equal to or greater than 80 % and which are no more than 1 m from the transect line. For each quadrat, the relative percent cover of crustose coralline algae, calcareous macroalgae and fleshy macroalgae was estimated. An estimation of the average canopy height was calculated for both calcareous and fleshy macroalgae by taking an average of at least five measurements for each. To give an estimate of the level of coral recruitment, the number of small colonies (maximum diameter # 2 cm) within each quadrat was recorded and identified where possible. As a measure of rugosity, the maximum reef relief was also measured at each of the five points along each transect. A minimum of 30 quadrats and relief measurements were made at each site with a total of 602 overall. In addition, densities of the Caribbean long-spined sea urchin *Diadema antillarum* (adult and juvenile) were recorded within a 1 m belt along each transect.

2.5. STAKEHOLDER WORKSHOP

Before leaving the study area a workshop was held for local stakeholders, including representatives from local government, NGO's, the fishing community and the tourism sector. The rationale, methodology and preliminary findings of the study were summarised in a presentation before an open discussion forum was initiated in order to consider the implications of the study and the possible uses of the information provided.

2.6. DATA ANALYSIS

Data was entered into a custom designed Access database and analysed using the statistical software package Minitab. Data for coral and algal cover was normally distributed as shown by Ryan-Joiner tests and was also shown to have homogeneity of variance with both Levenne's and Bartlett's tests. Therefore, ANOVA was used to test for significant differences in these parameters between sites. However, the remaining data followed non-normal distribution patterns which could not be corrected by appropriate transformations. Hence, non-parametric statistics were used to test for significant variability between sites for these parameters.

3. RESULTS

3.1. CORAL COVER

In order to make results comparable to other AGRRA sites the coral cover data was adjusted to remove the effect of sand (% adj. coral cover = % coral cover (100 / 100 – sand cover) before analysis. Mean percent cover of live coral, algae, bare substrate and other biological classes at each site is shown in Fig. 3. A one-way ANOVA revealed significant differences in coral cover between sites ($F = 49.52$, $p < 0.0001$), and a Tukey's pairwise comparison test showed that deeper (BCI 4-7) or more sheltered (LCI 1) sites dominated by *Montastraea annularis* exhibited significantly higher coral cover with mean values ranging from 30.23 ± 2.02 % (n = 10) at LCI 1 to 49.14 ± 3.82 % (n = 10) at BCI 4, than the shallow, wave-exposed sites on both islands (BCI 1,2 & 8 and LCI 2-6) where mean cover varied from as low as 8.83 ± 3.02 % (n = 6) at BCI 8 to 21.13 ± 4.10 % (n = 9) at LCI 5. In addition, the mean percent of bare substrate was conspicuously higher at the sites with low coral cover, with values ranging from 13.77 ± 3.26 % (n = 13) at LCI 2 to 32.25 ± 5.51 % (n = 6) at BCI 8. In contrast, the cover of bare substrate was no greater than 4 % at the deeper or more sheltered sites. Coral cover at Blowing Rock was lower than the deep sites at Great Corn (BCI 4-7) and comparable to the shallow exposed sites with a mean value of 21.75 ± 6.57 % (n = 6). Site BCI 4 had significantly higher coral cover than any other site surveyed.

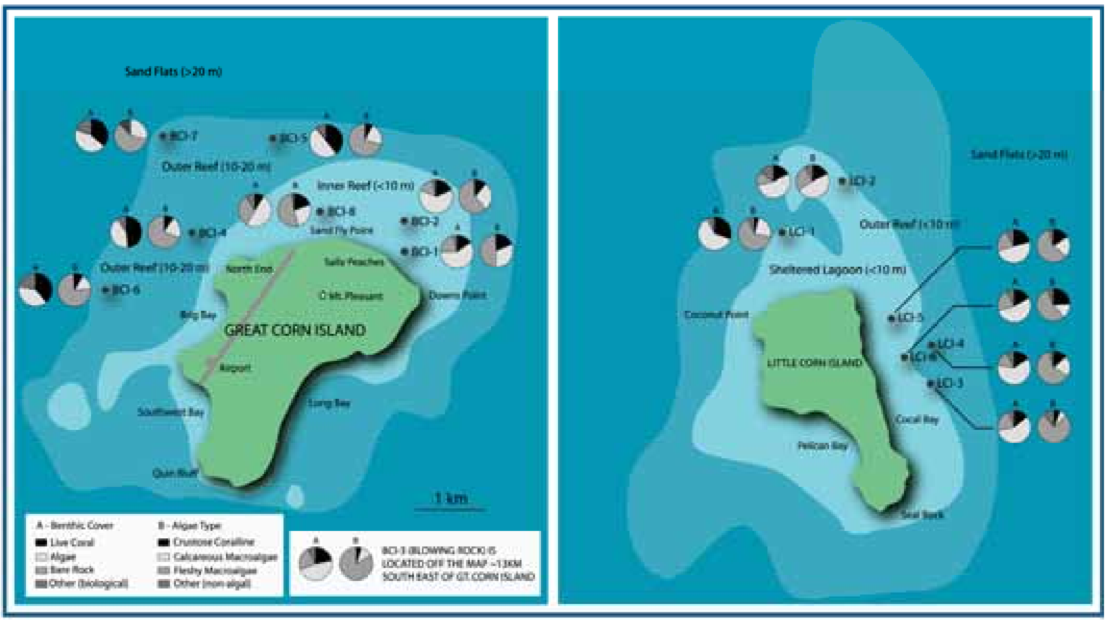


Figure 3. Thematic map of the Corn Islands with two sets of pie charts: A - shows percent cover of live coral, algae, bare rock and other biological classes (e.g. sponges, gorgonians and Milleporids); B - shows relative percent abundance of the three types of algae (crustose coralline, calcareous and fleshy macroalgae) at each of the surveyed sites.

3.2. CORAL COMMUNITY STRUCTURE

The scleractinian colonies sampled included a total of 27 species, although competitive dominance was evident at most sites and the majority of colonies sampled were within a relatively small group of taxa, with just four species accounting for 77.9 % of corals surveyed (in descending order of abundance: *Montastraea annularis*, *Porites astreoides*, *Agaricia agaricites* and *P. porites*). The remaining coral taxa encountered were either occasional (*Diploria strigosa*, *M. faveolata*, *D. clivosa*, *Acropora palmata*, *M. cavernosa* and *Siderastrea siderea*), contributing between 1.9 % and 4.2 % each; or rare with relative abundances between 0.05 % and 0.7 %. *Montastraea annularis* was the most dominant species at most of the deeper sites on Great Corn (BCI 4-6) and the patch reef at Little Corn (LCI 1), contributing between 34 % (BCI 6) and 56 % (LCI 1 & BCI 4) of the colonies sampled. The remaining sites can be divided into three general categories: (1) dominated by *Porites astreoides* (LCI 2-6 & BCI 8); (2) co-dominated by *P. astreoides* and *Agaricia agaricites* (BCI 1 & 2); (3) or of a relatively even community distribution (BCI 3 & 7).

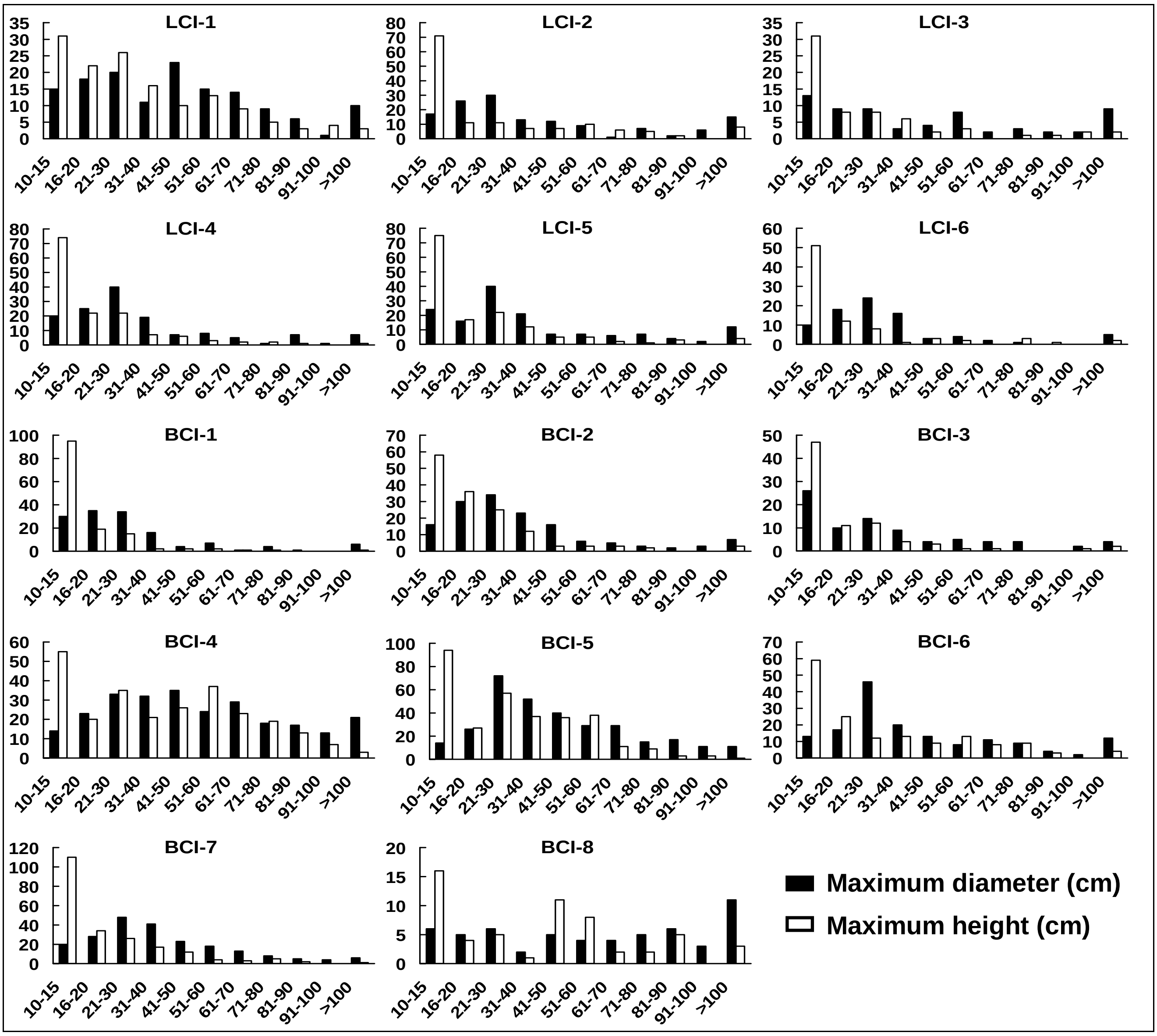


Figure 4. Size-frequency distributions for maximum diameter and maximum height measurements of all coral colonies surveyed at each site [x-axis = size class (cm); y-axis = frequency].

3.3. CORAL SIZE-FREQUENCY

Kruskal-Wallis tests showed that significant differences in mean maximum colony diameter and height did occur between sites (Diameter: $H = 156.37$, $df = 13$, $p < 0.0001$; Height: $H = 251.30$, $df = 13$, $p < 0.0001$). The frequency distributions for maximum colony diameter and height at each site with all coral heads pooled together are shown in Fig. 4. In general, the patch reef at Little Corn (LCI 1) and the deeper sites on Great Corn Island's outer reef (BCI 4-6) had a higher frequency of colonies within the larger size classes (> 40 cm) than shallow exposed sites on both islands (LCI 2-6 and BCI 1 & 2), with the exception of site BCI 8 which appears to have a significant proportion of colonies within the largest size class. However, following AGRRA protocol, colonies which are 'standing dead' (100 % mortality but intact) and identifiable are included in the survey and the majority of colonies measured at this site were in this category. Significant differences occurred in mean maximum diameter of *M. annularis* colonies between sites where this species dominated (LCI 1, BCI 4-6) as shown by a Kruskal-Wallis test ($H = 31.82$, $df = 3$, $p < 0.0001$). The largest colonies were found at BCI 4 with a mean of 66.50 ± 4.67 cm (n = 146), and the smallest at LCI 1 with a mean of 46.51 ± 6.51 cm (n = 80). A Kruskal-Wallis test showed significant differences also occurred in the mean maximum diameter of *Porites astreoides* between sites ($H = 41.60$, $df = 12$, $p < 0.0001$) with values varying from 18.38 ± 3.24 cm (n = 16) at BCI 3 to 29.57 ± 4.32 cm (n = 35) at BCI 5. However, there did not appear to be any general trends.

3.4. PARTIAL MORTALITY

Mean values for estimates of percent 'old' partial mortality per coral colony range from 7.21 ± 3.63 % (n = 140) at LCI 4 to 56.84 ± 11.17 % (n = 57) at BCI 8 (Fig. 6). However the peak value at site BCI 8 represents an unusually high level of historical mortality for the sites surveyed since mean percentages at the remaining sites do not reach values greater than 20 %. A Kruskal-Wallis test revealed that the variability between sites was significant ($H = 151.12$, $df = 13$, $p < 0.0001$) and a subsequent test on the data set without including values from site BCI 8 showed that significant differences between sites remained ($H = 70.69$, $df = 12$, $p < 0.0001$); however, no obvious trends are discernable with some sites in each broad category ('shallow *Porites astreoides* dominated' and 'deep *Montastraea annularis* dominated') having relatively high values and others having relatively low values. Values for mean percent 'recent' partial mortality were generally lower than for 'old' mortality with a range from as low as 0.78 ± 0.82 % (n = 64) at LCI 3 to 7.99 ± 2.50 % (n = 214) at BCI 7. There were significant differences between sites as shown by a Kruskal-Wallis test ($H = 70.73$, $df = 13$, $p < 0.0001$); however, as with 'old' mortality there does not appear to be any obvious trends. The two highest values were exhibited on the deep outer fringing reef at Great Corn (BCI 4 & 7) and the lowest values were found at some of the shallow fringing reef sites at Little Corn.

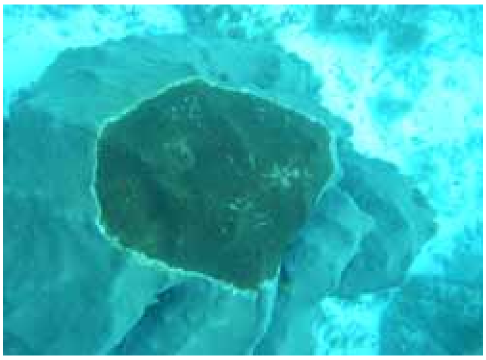


Figure 5. A colony of *Montastraea franksii* exhibits partial mortality caused by the boring sponge *Cliona langae*.

Kruskal-Wallis tests also revealed significant differences in both 'old' ($H = 408.99$, $df = 26$, $p < 0.0001$) and 'recent' ($H = 133.71$, $df = 17$, $p < 0.0001$) partial mortality between the different species of colony examined with data from all sites pooled. *Acropora palmata* exhibited the highest mean percent 'old' mortality (54.90 ± 11.90 %, n = 50); however, this species was poorly represented in the samples due to its relative rarity. Of the more abundant corals (>100 colonies surveyed overall) *Montastraea annularis* had the highest mean percent 'old' partial mortality (26.14 ± 2.74 %, n = 524) and 'recent' partial mortality (5.83 ± 1.18 %, n = 524), whereas *Porites astreoides* had relatively low values for both parameters with means of 3.64 ± 1.08 % (n = 517) and 1.16 ± 0.58 % (n = 517) respectively.

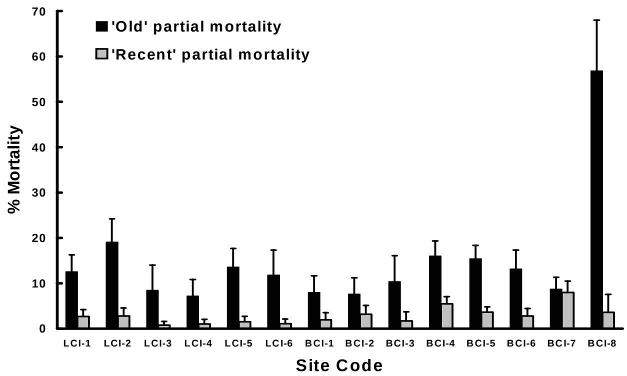


Figure 6. Mean percent 'recent' and 'old' partial mortality per coral colony at each site showing 95 % confidence intervals.

3.5. TOTAL MORTALITY

Figure 7. A colony of *Montastraea faveolata* affected by white plague.

The mean proportion of recognisable colonies that had suffered total mortality remained below 5 % at all of the surveyed sites with the exception of BCI 8 where over 40 % of the colonies sampled were dead (23 out of 57), representing approximately a third of all dead colonies surveyed on the island's reefs (total no. dead colonies sampled = 70). Chi-square analysis showed that this was significantly greater than at the other sites surveyed (ι^2 = 239.62, critical value = 10.83 where p = 0.001 and df = 1). Of the dead colonies surveyed, the vast majority were *M. annularis* (45.7 %), although *Acropora palmata* also represented a large proportion (25.7 %), followed by *Diploria strigosa* (8.6%) and *D. clivosa* (7.1 %). 36 % percent of *A. palmata* colonies which were surveyed had suffered total mortality.

3.6. CORAL DISEASE

A total of 58 colonies exhibiting signs of disease were observed during the surveys, representing 2.79 % of the sampled community and 72.4 % of all diseases reported were white plague (Fig. 7) on *Montastraea annularis* and, occasionally, *M. faveolata*. This particular disease was most prevalent at sites BCI 4 & 5, with 5.4 % and 4.8 % of sampled colonies affected respectively. These values were shown to be higher than average for the sites surveyed, including other sites dominated by *M. annularis* (LCI 1, BCI 6, 7), with a chi-square test (BCI 4: ι^2 = 10.96, critical value = 10.83 where p = 0.001 and df = 1; BCI 5: ι^2 = 4.46, critical value = 3.84 where p = 0.05 and df = 1). 8.6 % of coral disease observations were of white spot / pox on *Acropora palmata*, with LCI 2 as the worst affected site (1.4 % of colonies affected). An equal percentage of observations were made of dark spot disease on *Siderastrea siderea* with Blowing Rock (BCI 3) having the most affected colonies (2.4 %). Black band (BB), white band (WB) and yellow blotch (YB) were relatively rare with only two observations recorded for each (BB: BCI 2 & LCI 5; WB: LCI 2 & LCI 5; YB: LCI 5).

3.7. OTHER MORTALITY

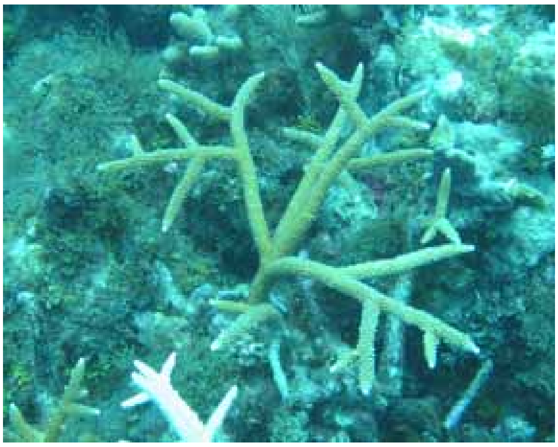


Figure 8. An area of reef where many coral colonies have been overgrown by macroalgae at Little Corn Island. Several branches of the *Acropora cervicornis* colony were affected near the base.

Of the other identifiable sources of coral mortality algal overgrowth was the most prevalent with 3.4 % of all colonies affected (Fig. 8). The highest percentage of overgrown colonies was found at BCI 7 (12.6 %) which was shown with a chi-square test to be significantly higher than the average for the sites surveyed (ι^2 = 54.93, critical value = 10.83 where p = 0.001 and df = 1).

The only sites which appear to be unaffected by algal overgrowth are LCI 4, BCI 6 and BCI 8. The boring sponge *Cliona* sp. was also responsible for coral mortality at half of the sites, with the highest percentage affected at BCI 8 (10.5 %). Storm damage was evident at all the shallow sites with the exception of LCI 1, although affected colonies were only occasionally encountered on transects. Occasional observations were also made of parrotfish grazing and damage as a result of damselfish bites.

3.8. CORAL BLEACHING

Observations of bleaching were occasional with a mean of 0.9 % coral colonies affected. The worst affected site was BCI 5 with 2.2 % of sampled colonies exhibiting pale or partially bleached tissues, generally in *Agaricia agaricites*.

CORAL RECRUITMENT

The density of coral recruits varied considerably between sites (Fig. 9), ranging from zero at LCI 6 to 1.60 ± 0.48 (n = 55) per 25 cm^2 quadrat at BCI 5 (6.4 m^{-2}). A Kruskal-Wallis test revealed that inter-site differences were significant (H = 160.95, df = 13, $p < 0.0001$). Recruit density was consistently low at sites around Little Corn, whereas examples of both deep (BCI 4-6) and shallow (BCI 8) sites at Great Corn had mean densities above 4 m^{-2}.

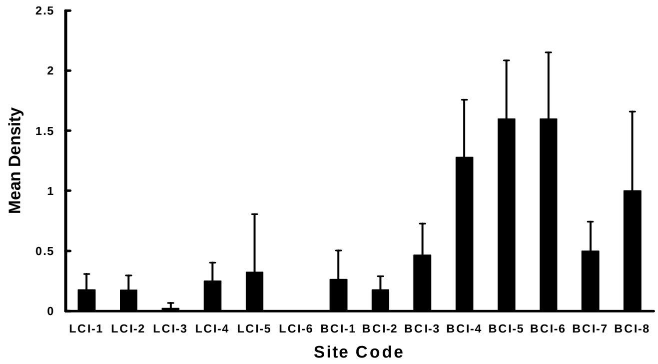


Figure 9. Mean density of scleractinian coral recruits per 25 cm^2 quadrat at each site showing 95 % confidence intervals.

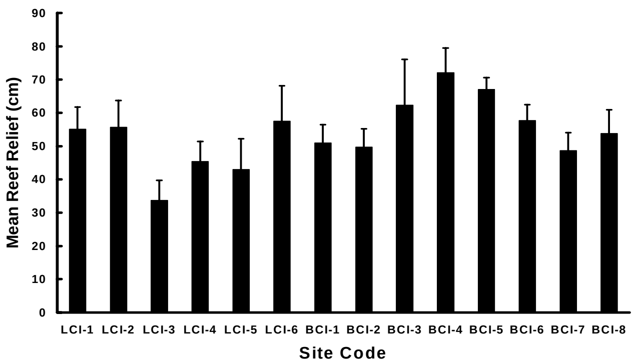


Figure 10. Mean maximum reef relief in centimetres at each site showing 95 % confidence

3.9. REEF RELIEF

The maximum relief at all sites remained relatively high with values ranging from 33.69 ± 5.99 cm (n = 45) at LCI 3 to 72.12 ± 7.33 cm (n = 50) at BCI 4 (Fig. 10). A Kruskal-Wallis test revealed that there were significant differences between sites (H = 103.66, df = 13, $p < 0.0001$); however, there does not appear to be a general pattern other than the fact that the highest values were found on the deep reef at Great Corn and the lowest on the shallow fringing reef at Little Corn.

3.10. ALGAL COVER

Algae represented the dominant benthic class at all sites surveyed (Fig. 11). Percent cover of algae at each of the sites is shown in Fig. 4. A one-way ANOVA revealed that significant differences in the cover of algae were present between sites (F = 7.18, $p < 0.0001$), although perhaps not as marked as with the coral cover data. Tukey's pairwise comparison revealed that the lowest algal cover was generally exhibited at sites on the deep outer reef of Great Corn, with the possible exception of site BCI 5. Mean algal cover values for sites BCI 4 (41.30 ± 4.96 %, n = 10), BCI 6 (39.08 ± 5.50 %, n = 6) and BCI 7 (43.87 ± 7.44 %, n = 8) were all significantly lower than at their counterpart habitat on Little Corn, LCI 1 (61.60 ± 5.50 %, n = 10). The highest algal cover was observed at site BCI 2 with a mean value of 62.33 ± 5.28 % (n = 9).

Figure 11. Fleshy macroalgae dominates the benthos on a reef at Little Corn Island.

3.11. ALGAL COMMUNITY STRUCTURE

Relative abundances of the three main types of algae found at each site are shown in Fig. 13. Following AGRRA protocol, quadrats were treated as independent samples and data was pooled for each site. Algal community structure was shown to be significantly variable from site to site with positive Kruskal-Wallis test results for differences in abundance of crustose coralline algae (H = 123.82, df = 13, $p < 0.0001$), calcareous macroalgae (H = 63.41, df = 13, $p < 0.0001$) and fleshy macroalgae (e.g. Fig. 13) (H = 107.35, df = 13, $p < 0.0001$). In general, the abundance of

Figure 12. *Stypopodium zonale*, an abundant fleshy brown macroalgae on the reefs of the Corn Islands

crustose coralline algae is higher in the shallow, more exposed sites (e.g. LCI 2,4,5,6 & BCI 1,8), with a peak value at LCI 6 (24.14 ± 9.59 %, n = 35). The deep sites at Great Corn (BCI 4-7) and the sheltered site at Little Corn (LCI 1) had relatively low cover with values ranging from zero (BCI 7) to 9.60 ± 3.97 % (n = 50) at BCI 4. The mean cover of calcareous algae was highly variable between sites with values ranging from 7.16 ± 3.63 % (n = 45) at LCI 3 to 48.97 ± 9.21 % (n = 63) at LCI 2, although there does not appear to be any general trends. With mean cover ranging from 49.55 ± 10.85 % (n = 38) to 75.89 ± 6.65 % (n = 45), fleshy macroalgae was the principal type of algae at all but one of the sites surveyed (LCI 2: mean = 25.87 ± 8.59 % (n = 63).

Mean canopy length of fleshy macroalgae varied between 2.97 ± 0.39 cm (n = 30) and 8.04 ± 1.54 cm (n = 44), while calcareous macroalgal length was slightly less variable, ranging from 2.48 ± 0.29 cm (n = 29) to 6.38 ± 3.33 cm (n = 40) (Fig. 13). These between-site variations were shown to be significant with positive Kruskal-Wallis test results (fleshy: H = 117.35, df = 13, $p < 0.0001$; calcareous: H = 10.62, df = 13, $p < 0.0001$). The most developed fleshy algal community appears to be at some of the sites on Little Corn where canopy length is greatest, namely LCI 1, 2, and 4.

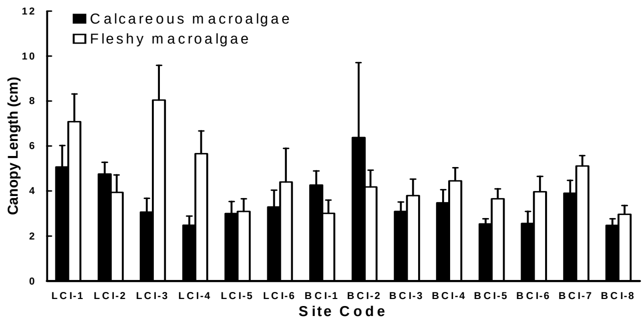


Figure 13. Mean canopy length of calcareous and fleshy macroalgae per quadrat in centimetres at each site showing 95 % confidence intervals.

3.12. DIADEMA ABUNDANCE

Mean abundance of *Diadema antillarum* per 10 m^2 belt transect was shown to be significantly different between sites using a Kruskal-Wallis test (H = 66.51, df = 13, $p < 0.0001$) (Fig. 14). In general, the species was absent or in extremely low abundance at sites dominated by *Montastraea annularis* (LCI 1 & BCI 4-7). A total of 35 transects were conducted on the outer reef at Great Corn (BCI 4-7) covering an area of 350 m^2 with only three individuals counted overall. However, observations of *Diadema* were made at all shallow exposed sites (LCI 2-6 and BCI 1, 2 & 8), with mean densities per transect varying from 0.57 ± 0.58 (n = 10) to 10.5 ± 10.00 (n = 10), although intra-transect variability was clearly high as shown by the large confidence intervals.

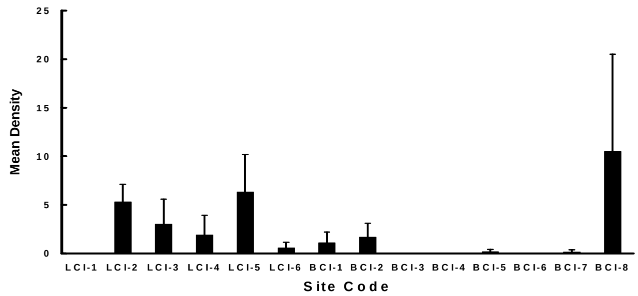


Figure 14. Mean density of adult and juvenile *Diadema antillarum* per 10m^2 belt transect at each site showing 95 % confidence intervals.

4. DISCUSSION

The ability to gain a broad overview of the condition of the reefs surrounding the Corn Islands, and hence fulfil the primary objective of the study, depends largely on whether spatial patterns in the reef health indicators are apparent from the results. However, it is important to consider the likelihood that some between-site differences in measurements of AGRRA parameters may be due, in part, to variability in habitat type. Coral reef ecosystems are inherently heterogeneous on all but the very smallest of scales and this inconsistency may confound the results of an ecological study within these complex habitats (Fig. 15).

Figure 15. A typical 'deep' (10-15 m) coral reef site at Great Corn Island exhibiting the characteristic heterogeneity of these habitats.

Figure 16. A degraded habitat on the outer reef at Little Corn Island exhibiting low cover and biodiversity of coral, high colony mortality, severe macroalgal overgrowth and low abundance and biodiversity of reef fish.

From a biological cover perspective the shallow exposed sites on the inner fringing reef at Great Corn Island and the outer fringing reef at Little Corn appear to be more degraded (Fig. 16) relative to deeper sites on the outer reef at Great Corn (Fig. 17). The shallow habitats exhibited low cover of live coral and relatively large percent area of bare substrate, whereas deeper sites had a relatively high cover of coral for the region [93]. According to previous observations by Roberts and Suhayda [61] the shallow reef zones of both islands were once dominated by *Acropora palmata*, whereas during the present study this species was relatively rare (Fig. 18). The species may have suffered from a mass mortality as a result of the Caribbean-wide epidemic of white band disease [93], Hurricane Joan which devastated the islands in 1988, or a combination of both impacts. The abundance of coral which is intact but dead ('standing dead') is an important indicator of past disturbance events and the proportion of *A. palmata* colonies standing dead was unusually high. This species also had the highest mean partial mortality of all colonies surveyed and a very high proportion of colonies affected by white spot/pox. It is likely that a shift in community structure has occurred in the shallow reef zones of both islands due to losses of this major reef-building coral. Nevertheless, some small recently-recruited *A. palmata* colonies did exist, albeit rarely, showing that some recruitment has occurred in the past few years (Fig. 18).

Figure 17. A relatively healthy habitat on the 'deep' (10-15 m) outer reef at Great Corn Island exhibiting high cover and biodiversity of coral.

Size-frequency distribution of colonies at the shallow sites is skewed towards the smaller size classes, indicating a possible imbalance in the species assemblage with a propensity for small colonies. The competitive dominance of the medium sized species *Porites astreoides* and / or *Agaricia agaricites* evident at these sites further supports this view.

The abundance of coral recruits is an important indication of a reef's potential for growth and recovery after major disturbances [61]. Recruitment was relatively high for the region at the deeper sites dominated by *M. annularis* on Great Corn, rising above the mean of 4 m^{-2} for 20 other AGRRA sites in the Caribbean [93]. However, Little Corn Island's reefs and two of the shallow sites on Great Corn (BCI 1 & 2) had far lower than average recruitment densities. The site with the lowest cover of live coral (BCI 8) had a recruit density which was compared to other sites in the region, thus highlighting its potential for recovery.

Figure 18. A relatively healthy stand of Acropora palmata at Little Corn Island. This once dominant species was very rare at most sites.

Partial 'old' colony mortality was comparatively low for the region [93] at all except the most degraded site (BCI 8). The partial 'new' coral mortality was highest at locations on the deep outer reef which is most likely due to the very high frequency of white plague disease affecting *M. annularis*, the most dominant coral at these sites. *M. annularis* also has the highest proportion of colonies standing dead and the highest mean percent 'new' mortality of all species, further supporting this observation. Interestingly, *M. annularis* colonies at the only site where the species was dominant on Little Corn were unaffected by the disease (LCI 1).

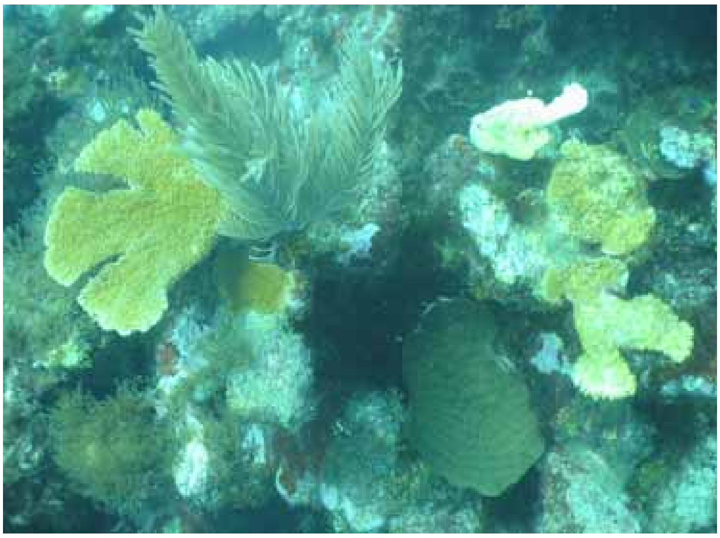


Figure 19. Young Acropora palmata colonies on a reef at Little Corn Island showing that recruitment has been occurring in the past few years.

Macroalgal cover remained the dominant benthic class and canopy length exceeded values found at other AGRRA locations in the Caribbean [93] at all surveyed sites. This apparently well developed algal community, dominated by opportunistic and fast growing fleshy macroalgae, may suggest that the herbivory process has been upset by overfishing or as a result of the low abundance of *Diadema antillarum*. Algal overgrowth was also a primary cause of coral mortality on the island's reefs, particularly on the outer reef at Great Corn (BCI 5), supporting the possibility of reduced grazing pressure.

5. CONCLUSIONS

A number of reef health parameters clearly indicate that coral reefs around the two islands are in a variable state of health. It would seem that reef sites are experiencing different health problems depending on the habitat type. Shallow exposed sites appear to have undergone a community phase shift as a result of the loss of the major reef-building coral *A. palmata*. Whereas deeper sites on the outer reefs of Great Corn Island seem to be suffering from a combination of white plague disease and macroalgal overgrowth possibly as a result of decreased herbivory. However, a long-term monitoring programme incorporating temporally explicit data in addition to spatially explicit data would be required to reveal the presence of human influences on the reefs such as nutrient pollution.

The information provided by the present study provides a snapshot of reef health at selected sites around the Corn Islands and may prove useful as baseline data upon which to build a monitoring programme following the same methodology. The study also represents the first quantitative investigation of reef health to be conducted in Nicaragua and the data will be included in the AGRRA regional database for the wider Caribbean region.

6. ACKNOWLEDGEMENTS

This research was supported by the Natural Environment Research Council, The Royal Geographical Society with the Institute of British Geographers, The University of Newcastle Exploration Society, The Rufford Foundation, PADI Project Aware, Coral Cay Conservation, The Gilchrist Educational Trust, Brooksbank Valves Ltd, P&O, RAAS-Asdi-RAAN, Dive Little Corn and Casa Iguana. I would also like to thank my supervisor Dr. R. Foster-Smith for all his advice and support throughout, Dr. J. Bythell for his advice on statistical analysis, Mr. J. Ryan for his support and invaluable information relating to the reefs of the Corn Islands, Dr. R. Ginsburg and Dr. J. Lang for their advice concerning the AGRRA surveys and the survey team for their tireless efforts in collecting the data: Y. Zapata, A. Segura, D. Montalban, I. Wilson, D. Hume, R. Velterop and T. Daw.

ASSESSMENT OF THE CORN ISLANDS' CORAL REEFS

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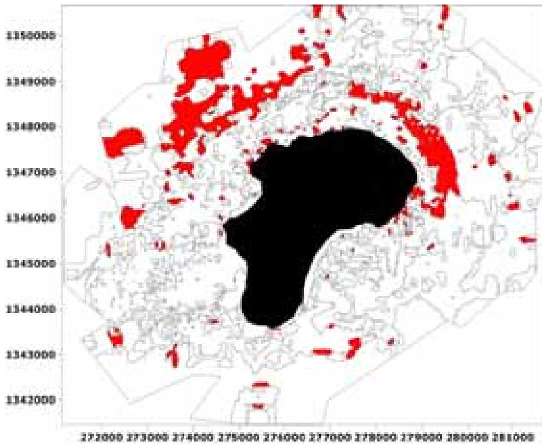
CORAL REEF HABITAT

Image 1. A fringing reef on little Corn Island dominated by *Acropora palmata* colonies.

GREAT CORN ISLAND



LITTLE CORN ISLAND

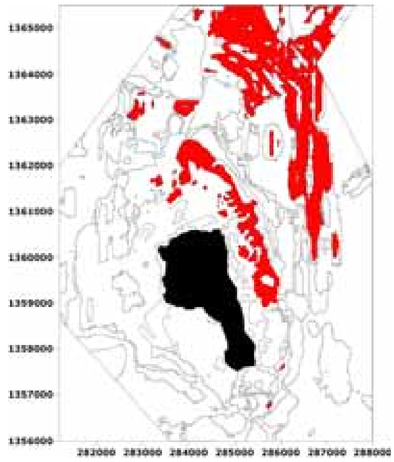


Figure 1. The predicted distribution of coral reefs around Great Corn Island and Little Corn Island based on Landsat TM Satellite and RoxAnn AGDS (acoustic) remote sensing surveys.

Accuracy Note: The signatures used in supervised classification of both the Landsat and RoxAnn data were almost clear of overlap and so there is little chance of misclassification, however attention should be paid to the tracking intensity of the RoxAnn survey (Section B, Map 2), Very little surveying was undertaken on the north east of Little Corn and the predicted outer extent of coral reef in this area may be inaccurate, ideally further surveys should be undertaken in this area, (if this is not possible then at least an accuracy assessment).

1. LOCAL VALUE OF THE CORN ISLANDS' CORAL REEFS

1.1. SHORELINE PROTECTION:

One of the principle benefits of the Corn Islands coral reefs is their role as a coastal barrier protecting the islands beaches and wetlands from storm and hurricane impacts and coastal erosion [94]. The capacity of the coral reefs to dissipate wave energy also creates the islands lagoons and near shore sedimentary environments creating favourable conditions for the growth of sea-grasses around the islands [95, 96]. The reefs protect the wetlands and seagrass habitats which assimilate pollution and they prevent salinisation of the islands fresh water aquifer. A decrease in coastal protection resulting from decline of the islands coral reefs would therefore threaten the beaches and wetlands which would in turn affect water quality and coastal agricultural productivity due to groundwater pollution.

1.2. ECO-TOURISM:

The coral reef habitats of the Corn Islands have a huge potential value for the eco-tourism industry. In the year 2000 more that 23,000 visitors visited the islands with an estimated $12.8 million contribution to the national economy. At present, there are only three scuba diving centres on the two islands; and although only around 8% of tourists who visit the islands dive on the reefs almost all who visit come are there to enjoy the resources that depend directly on the health of the reefs: fishing, the beaches, surfing, observation of flora & fauna [97]. With the declining fishery industry, eco-tourism is the most likely alternative livelihood for the islands and the industry is set to increase further. Coral reefs are also responsible for the generation of fine coral sand supplying shores with the white sand that is one of the main attractions in beach tourism [98].

1.3. LOBSTER HABITAT:

The coral reefs around the Corn Islands are likely to be an important post settlement habitat for juvenile spiny lobsters and adult lobsters. Sponges, crevices and solution holes and branching corals provide protection from predators and reefs support plentiful prey species as do the seagrass habitats that the reefs provide shelter for [6, 99]. A study of the lobster juvenile lobster population in Miskito Cays in the north of Nicaragua's Caribbean coast found that coral reefs were the only post-settlement habitat utilised by juveniles [100]. The spiny lobster (*Panilarus argus)* fishery is the primary source of income for the Corn Islands population and the islands reefs are therefore an important economic resource if they maintain recruitment of juveniles to the fishery. Any threat to the coasts lobster nursery habitats will decrease the productivity of the fishery by creating a bottleneck [101].

1.4. FISH HABITAT:

The islands coral reefs support a wide range of fish species including commercially important species of snapper (*Lutijane*) and grouper (*Serranidae*) which are fished primarily during the lobster closed season. The health of the reef ecosystem depends on a number of other fish species. Parrotfish (*Scariade*) contribute to ultra fine coral sediments, while herbivores such as damlsefish (*Pomacentridae*) and surgeonfish (*Acanthuridae*) control the algal population on the reef [102]. Because of the dominance of the (mainly offshore) lobster fishery it seems that the islands fish populations are still relatively intact. These populations include a number of charismatic species of sharks and rays which are an important asset to dive tourism.

1.5. WASTE TREATMENT:

Coral reefs have a limited ability to detoxify and sequester human wastes. Microbes living on reefs can for example detoxify hydrocarbons turning them to carbon dioxide and water [103]. However, this capability is likely to be limited where there is persistent of chronic pollution [104].

2. POTENTIAL VALUE OF THE CORN ISLANDS' REEF HABITATS

2.1. HAWKSBILL TURTLE HABITAT:

Hawksbill turtles are a globally endangered species. They are spongivores and feed solely on the sponges that coral reefs support. They are known to breed on the nearby Pearl Cays [105] and it is a possibility that the Corn Islands reefs are an important feeding area for these turtles. Spongivory may be an important factor in maintaining the health of the reef ecosystem by releasing corals from competition with sponges [106]. If they do feed near the islands, the Hawksbills may therefore help to maintain the health of the reef ecosystem. Furthermore, they would also be an important asset to the dive-tourism industry as a charismatic species.

However, in Nicaragua, Hawksbill turtles are also legally fished and turtles have cultural significance as a food for indigenous Indian groups on the Caribbean coast. Furthermore, because of their low commercial value, turtle meat is also provides a source of cheap protein for the subsistence of poorer communities.

2.2. THE CURIO TRADE:

Antipatharians or black corals are found in deeper waters around the Corn Islands and are harvested on a small scale for artisanal jewellery manufacture. Turtle shell has also been observed on sale by some artisans and it is likely that other varieties of corals & shells are used such as mother of pearl (*Trochus spp*).

2.3. AQUARIA: LIVE FISH / LIVE ROCK TRADE:

There is some anecdotal evidence of a trade is live fish for aquaria on the Corn Islands [60]. However, it is unknown how extensive this practice is in Nicaragua, what methods are used in the capture and preservation of the fish or where they are exported to. A further possible extension of this aquaria fishery is the live-rock trade. Live-rock is a term used by aquarists and the marine aquarium industry to describe hard substrate colonized by sessile marine invertebrates and plants [107]. Advances in salt water aquaria technology have created a growing demand for live-rock in especially in America where supply in-country is limited by strict regulation on coral extraction.

2.4. COLLECTION FOR BIOMEDICAL RESEARCH:

The biodiversity associated with the reef environment has also produced an array of chemical compounds, evolved largely for defence purposes, which have significant medical and research potential and are very different from the great bulk of biocompounds found in land-based organisms. These include antimicrobial, antiviral, cardioactive, cytotoxic, neurophysiologic, coagulatory and anticoagulatory and antibiotic. For example out of over 2,000 species of Cnidarians tested, 40% were found to be active anti-cancer agents and particularly high yields of anti-cancer products have been found in organisms tested from Fiji, Australia, Grand Cayman and Puerto Rico

[108]. There is the potential for establishing bioprospecting surveys in the Nicaragua to assess the medical potential of the coasts' reef & marine resources.

2.5. CORAL MINING:

Coral reefs in other areas of the world been exploited for use as construction materials [109], for the creation of lime to regulate PH in agriculture [110] and for use as a fertilizer [111]. There is some anecdotal evidence that coral mining was an activity on the islands during the earlier part of the 20th century where coral was crushed and burnt to make lime for agriculture (most likely to increase the productivity of the palm oil industry). This practice seems to have ceased but may be re-established if agricultural activity increases on the islands.

3. THREATS TO THE CORN ISLANDS' CORAL REEFS

3.1. NUTRIENT ENRICHMENT:

The Corn Islands near shore reefs are thought to be connected to the islands aquifer through geological fissures [60, 86]. Population growth is increasing the levels of nutrient input into the islands wetlands and these may be leaching via the islands aquifer onto the reefs or flood waters washing into near shore coastal waters during the rainy season.

Increased nutrients from agriculture, fertilizers, wastewater and sewage discharge can disrupt the normal trophic structure and dynamics of coral reefs by artificially encouraging algal blooms. Algal blooms out compete or displace slower-growing organisms, such as corals and can result in the proliferation of organisms that compete with, or damage, corals (e.g., burrowing bivalves and boring algae and sponges). When combined with depleted stocks of herbivores; nutrient enrichment radically increases the chances of a phase shift and decline of the reef habitat as has occurred in many other Caribbean countries [102, 112].

3.2. CLIMATE CHANGE & SEA-LEVEL RISE

Growth of individual coral organisms is estimated between 1-20 cm/yr [113], and reef growth rates as a whole are known to be up to 1.5 cm/yr [114]. Based on these values, in optimal growth conditions, the islands' reefs may be able to keep pace with predicted sea-level rise. However; on the Corn Islands the greatest threat of sea level rise impacts on coral reefs is indirect:

The islands do not have centralised wastewater treatment and the islands' population has been growing rapidly in recent years [97]. The wetland areas therefore process the majority of the islands wastewater and sewage which enters the wetlands through groundwater seepage and runoff. Most of these wetlands are enclosed freshwater ecosystems located on the low level coastal areas [97] and some are exhibiting signs of nutrient pollution (See Badjeck - this study). Half of Corn Island lies below the 2m mark and the 50 cm rise in sea level which is predicted (at a conservative estimate) within the next century will likely inundate one third of the island [115]. Combine that with a predicted increase in storm frequency and intensity [115] and it seems highly likely that these freshwater wetland areas will be frequently inundated with seawater.

Saline intrusion into these freshwater ecosystems would stress the vegetation in these wetlands affecting their ability to process the increasing nutrient levels [116]. This would have implications for the islands fresh water supply and may also lead to increasing nutrient input onto near shore reefs which are already showing signs of nutrient loading (See: Hunt - this study), and thus further increases the risk of phase shift to macro-algae dominance [60, 102]. This also represents a positive feedback mechanism, as deterioration of the islands principle defence against storms (the coral reefs) further increases the risk of saltwater inundation of the wetlands and erosion of coastal barriers.

3.3. OVER-FISHING:

Overfishing of herbivorous reef fish is a major threat to reef health because it can result in macro-algal overgrowth of corals leading to the decline of the reef system through a process of phase shift which is one of the principle causes of reef decline in the Caribbean [102]. This is a particularly important threat in the Caribbean because herbivorous fish are now the principle grazers of macroalgae after wide spread disease resulted in a regional die-off of herbivorous *Diadema antillarum* sea urchins [117]. The dominance of the lobster fishery and the low relative value of herbivorous fish compared to carnivorous fish such as snappers, jacks and groupers on the Corn Islands do however mean the threat is currently minimal. Jamaican fish traps which are used by some fishers are however unselective [118] and therefore do pose a threat to these herbivorous fish populations. A further threat to reef fish populations is the possibility of fishers exploiting spawning aggregations which around the islands which can significantly reduce recruitment to the fishery and possibly impacting the ecological stability of the reefs.

The recent decline of the lobster fishery does represent growing pressure on the near shore reef fishery especially during the lobster closed season and if left unregulated and unmonitored there is the possibility of overfishing of reef fish populations which would impact the health of the ecosystems and the future economic potential of marine eco-tourism.

3.4. SEDIMENTATION:

Sediment can smother corals and high turbidity reduces light penetration onto the reef reducing the ability of the corals zooxanthelle to photosynthesize, both can lead to coral mortality or reduced growth rates [119]. Sediment also reduces the substrate available for corals or other larvae and therefore limits recruitment. The main source of sedimentation on the Corn Islands is from near shore runoff during the rainy season when the coastal swamp areas overflow. Corals can survive acute turbidity events but increases in the level of sedimentation such as agricultural land use change on the islands hill slopes or development projects such as the recent road construction project on Great Corn Island may contribute to smothering of the corals, increasing mortality.

Other potential sources of sediment include dredging for navigation or marinas, breakwaters and other shoreline protection measures, beach renourishment, sand mining, installations of pipelines and underwater cables.

3.5. DESTRUCTIVE FISHING PRACTICES:

Some fishers on the coast are thought to use chlorine to catch lobsters it is not known how extensive this practice is but such practices will result in coral mortality [63]. Fish and lobster traps may also cause physical damage to the reef as will handling of the reef by lobster divers [100].

3.6. AQUARIA: LIVE FISH / ROCK TRADE:

The live fish trade as documented in Pacific involves pumping toxic cyanide onto coral communities to stun reef dwelling fishes [120, 121]. If life fish are being caught using these methods on the Corn Islands it would have serious impacts on the coral reefs. The live rock trade in Florida was phased out because it is almost impossible to remove invertebrates without extracting at least some corals and it is difficult to set sustainable levels of extraction. Removing rock substrate also reduces the area available for corals to recruit and reduces the food available for some reef dwelling organisms and therefore threatens the sustainability of the reef.

3.7. CURIO TRADE

Black corals are a rare species and may become locally depleted very rapidly and because they are generally a deep water species as they become depleted in shallower waters, divers are forced to go deeper in search of remaining colonies increasingly risking their health as well as affecting the reef.

3.8. OIL / CHEMICAL POLLUTION:

Numerous chemicals likely enter coral reef habitats through point and non-point sources including land-based runoff from the islands landfill, effluents from fisheries processing, vessel discharges and oil and chemical spills. Their effects include disruption of normal biological and ecological processes, and retardation of coral reef community growth and recovery [122].

3.9. MARINE DEBRIS:

Reefs can easily become cloaked by large amounts of man-made debris lost by commercial fishing operations or emanating from other marine or terrestrial sources. These objects degrade reef health by abrading, smothering and dislodging corals and other benthic organisms, preventing recruitment on reef surfaces, and continued entanglement of fish, marine mammals, crustaceans and other mobile species. Any form of offshore dumping of waste from the Corn Islands' would therefore represent a threat to reefs.

3.10. INVASIVE ALIEN SPECIES:

Like all marine habitats, coral reefs are increasingly vulnerable to invasion by alien species that can cause lasting ecological and economic harm. The primary pathways of introduction into the Corn

Islands coral reef habitats are likely to include ships' ballast water, fouling organisms on movable marine equipment such as floating dry docks or ship hulls or marine debris.

3.11. PHYSICAL DAMAGE:

Vessel groundings and anchoring can directly destroy corals and reef framework. Branching corals are particularly susceptible to mechanical and physical damage. Davis [123], for example, estimated that Anchoring on top of coral reefs has damaged nearly 20 % of staghorn communities in the Fort Jefferson National Monument, Florida. In Bermuda a survey of ship groundings reported the obliteration of topographical features of coral reefs creating flat, barren areas with deposits of boulders, rubble and sparse surviving corals [124]. There are no mooring buoys around the Corn Islands and anchor damage to reefs may become a significant threat if tourism increases. Several tour operators currently visit the islands with small cruise ships and considering that damage that just one large anchor chain can do these larger vessels could cause significant impacts to the reefs.

3.12. CORAL DISEASE:

There are a range of diseases recorded as causing the mortality of corals including, blackband, white band, white plague, yellow blotch, aspergillosis (for a review see Green and Bruckner [125]). A recent report indicated that 66% of reports of coral diseases are recorded from the Wider Caribbean [126]. During surveys of Corn Islands reefs white band disease was recorded on several species. The cause of the disease is yet unknown but outbreaks are likely to increase in the islands corals if their resilience is lowered due to stress.

3.13. CORAL BLEACHING:

A variety of natural and human induced disturbances can affect the delicate balance between corals and their symbiotic microalgae (zooxanthellae) leading to the loss of these corals zooxanthellae (or their pigment) in a process called bleaching leading to mortality and reduced resilience of the reef ecosystem [127]. Bleaching is known to be induced by factors including temperature increase, salinity decrease, toxic heavy metals or high levels of UV radiation [127-130]. There was some evidence of bleaching on recent surveys of the Corn Islands shallow water reefs.

3.14. BIOPROSPECTING STUDIES

Ironically, scientists are capable of inflicting considerable, although localized, damage to coral reefs if collection is done carelessly. Reef corals are vulnerable to tissue injuries and these represent sites where algal infection can proceed. Biodiversity prospecting studies in Fiji are a good example of how research can help to conserve reef resources and provide financial rewards to help conserve the coastal and marine resources and maintain sustainability [131].

3.15. CORAL MINING:

Physical removal of corals from reef habitats has a serious detrimental impact on the ecosystem decreasing fish abundance and diversity, and losing its coastal protection value and increasing sediment pollution [132].

4. RECOMMENDATIONS FOR RESEARCH, MANAGEMENT & POLICY

4.1. RESEARCH

- Undertake a desk based study focusing on methods of monitoring and research.
- Develop a locally coordinated and participatory marine resources inventory, assessment and monitoring program which feeds into the national decision making structure.
- Undertake strategic research focused on the determinants of marine ecosystem health and recovery, including basic ecological processes, bleaching and disease, and best management practices for reef habitats.
- Use existing management authorities, universities and NGO's at the national, regional and local levels to undertake research and management.
- Develop and implement a comprehensive and appropriate outreach and education strategy for Nicaragua's marine and coastal habitats.

4.2. EDUCATION AND AWARENESS

- Develop a code of conduct for tourist divers and diving fishers to deal with physical damage to the reef.

- Educate specific user groups (e.g., fishers, vessel owners, divers, etc.) about ways to minimize the impacts of their specific activity on marine and coastal resources.
- Conduct socioeconomic studies to assess the perceived local importance of reefs and their threats to direct education, awareness and participatory research and management activities on the islands.
- Inform local and regional audiences of the linkage between their actions, marine and coastal ecosystem health and local livelihoods.
- Provide technical guidance to, landowners, local governments, and users to reduce land-based sources of pollution on an island watershed scale.

4.3. MANAGEMENT AND POLICY

- Adopt a science-based ecosystem approach to marine resource / coastal management that recognizes and builds upon important linkages between adjacent associated with coral reefs (wetlands, seagrass / algal beds).
- Employ adaptive management approaches that track and respond to environmental change and emerging threats.
- Ensure that management and policy measures reflect, and are sensitive to the local socioeconomic, political and cultural environment, and that they build an informed public engaged in choosing alternatives to activities that harm coral reefs.
- Where there is scientific uncertainty, take precautionary measures as appropriate to protect coral reefs.
- Apply marine zoning including marine protected areas and no-take ecological reserves - in order to protect and replenish coral reef ecosystems by minimizing harmful human impacts and user conflicts in important habitats.
- Develop, where needed, new legal mechanisms that protect, restore and enhance coral reef ecosystems.
- Monitor discharges from known point sources including onshore facilities and offshore sewage and industrial pipes, and vessel operations.
- Prevent, prepare for, and respond to pollution events on reefs and associated habitats to reduce impacts on reef ecosystems.
- Clean up existing concentrations of marine debris and address known sources in the future.
- Evaluate and mitigate major pathways of invasion by alien species.
- Improve law enforcement of illegal coral reef species trade.
- Ensure and proposed bioprospecting agreement benefits the local community and enhances the sustainability of the resource [131].

ASSESSMENT OF THE CORN ISLANDS' ALGAL HABITATS

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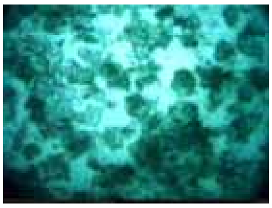
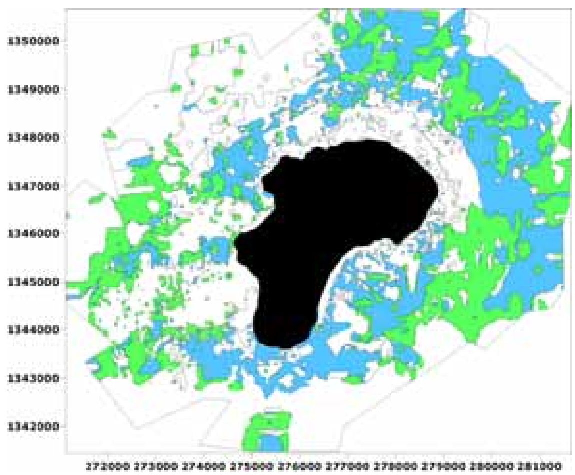
RUBBLE AND ALGAE



SAND AND ALGAE

Images 1 & 2. Examples of Algal Habitats.

GREAT CORN ISLAND



LITTLE CORN ISLAND

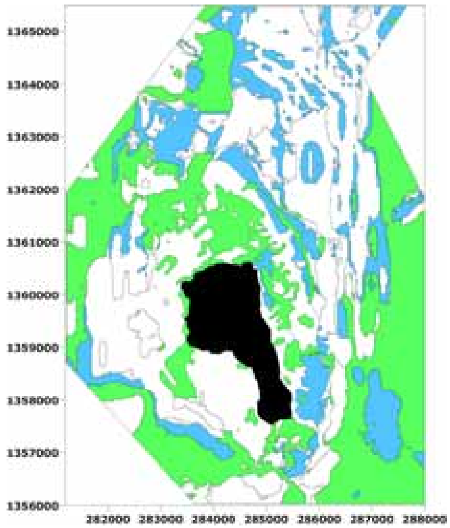


Figure 1. Predicted distribution of algal habitats around the Corn Islands based on supervised classifications of Landsat TM and RoxAnn AGDS imagery

Accuracy Note: Due to overlap in the acoustic signatures used in the RoxAnn classification, there is a high chance that the sand and algae habitat (green) may be sand that has been misclassified in deep water areas (>12m) around both islands. In shallow water around Great Corn, Sand and Algae may have been misclassified Rubble and Algae due to overlap in the spectral signatures used in the Landsat classification.

1. LOCAL VALUE OF THE CORN ISLANDS' ALGAL HABITATS

1.1. LOBSTER HABITAT:

Inshore areas protected from wave energy (for example on the sheltered western side of the islands) may be an important habitat for Spiny Lobster juveniles (Puerulus Postlarvae), especially if these areas are dominated by the red algae *Laurencia* and *Neogoniolithon.* As these species have been identified as particularly important in nursery habitat studies in Florida and Turks and Caicos [6, 133].

Note: Spiny lobsters spawn at sea before they settle on inshore habitats larvae are subjected to dispersion by oceanic currents[133]. This means that habitats that are identified as having few juveniles one year may have many the next depending on oceanic larval dispersion patterns.

1.2. COASTAL PROTECTION:

Much like seagrass beds, algal beds help to stabilise seabed sediments and protect the islands from coastal erosion during storm events.

2. THREATS TO THE ALGAL HABITATS AROUND THE CORN ISLANDS

2.1. SEDIMENTATION:

Sediment can smother algae as turbidity reduces light penetration reducing the ability of the algae to photosynthesize, leading to mortality or reduced growth rates. The main source of sedimentation on the sheltered algal habitats on the Corn Islands is from near shore runoff and potentially from increased erosion of beaches on the northern and eastern sides of the islands. Shrimp trawling and channel dredging near the islands may also increase suspended sediment levels and cause mechanical damage to these habitats [134].

2.2. MECHANICAL DAMAGE:

Anchor damage, dredging and other direct mechanical action can destroy algal habitats.

2.3. POLLUTION

The main pollution threat to algal habitats is from physical smothering from marine debris or due to an oil spill. This may result in anoxia or hypoxia which would seriously inhibit ecosystem functioning [135]. Nutrient enrichment in contrast actually enhances algal growth which can become a serious problem for other habitats.

3. RECOMMENDATIONS FOR RESEARCH AND MANAGEMENT

3.1. LOBSTER RECRUITMENT DESK STUDY:

- Undertake an extensive literature review of spiny lobster recruitment.
- Undertake a detailed assessment of the macro-algae species present within these algal habitats to assess their potential importance as recruitment areas and the impact / threat of sedimentation.

3.2. FIELD RESEARCH

- Establish a long-term ecosystem monitoring system to act as a baseline against which any impacts of future resource development plans (such as seaweed farming) can be measured.
- Undertake a spiny lobster larval recruitment study around the Corn Islands over a period of several years.

ASSESSMENT OF THE CORN ISLANDS' SEAFAN HABITATS

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RUBBLE, ALGAE & SEAFAN HABITAT

Image 1. Example of rubble, algae seafan habitat.

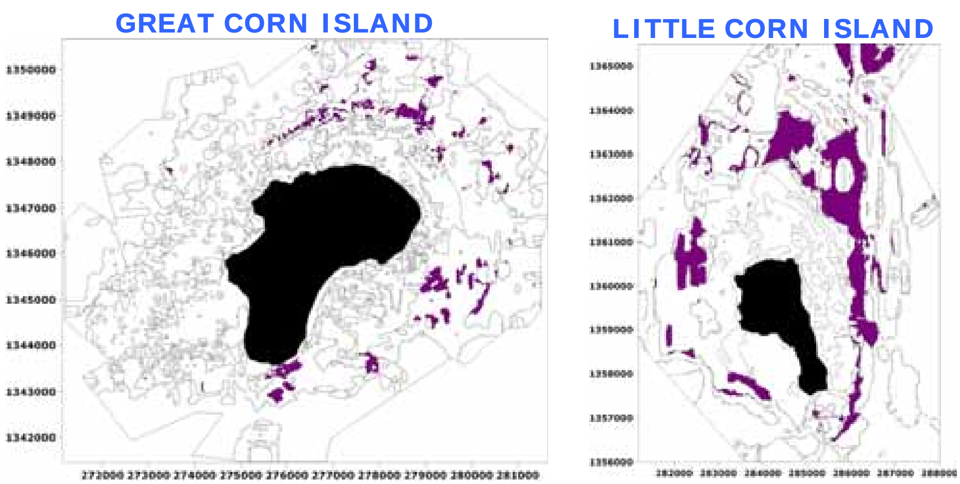


Figure 1. Predicted distribution of rubble, algae and seafan habitats around the Corn Islands based on supervised classifications of Landsat TM and RoxAnn AGDS imagery

Accuracy Note: The signatures used in supervised classification of both the RoxAnn data were overlapping with rubble and algae and seagrass. Contextual editing was used to overcome the seagrass overlap however there is still a high possibility that rubble and algae habitats were misclassified as rubble algae and seafans (and vice versa) in deep water areas (>12m). In shallow water areas (<12m) there is more of a possibility of misclassification with both of the other algal habitats (rubble & algae and sand & algae) due to the similarity of the optical signatures. Attention should be paid to the tracking intensity of the RoxAnn survey (Section B, Map 2), very little surveying was undertaken on the north east of Little Corn and the predicted outer extent of seafan habitat in this area may be inaccurate, ideally further surveys should be undertaken in this area, (if this is not possible then at least an accuracy assessment).

1. LOCAL VALUE OF THE CORN ISLANDS' SEAFAN HABITATS

1.1. LOBSTER & FISH HABITAT:

Seafans grow in areas of high currents and are commonly observed around the Corn Islands in seabed areas, which are otherwise sparse such as bare bedrock rock or sand. They provide refuge for a number of species and are likely to be an important habitat of adult lobsters in the deeper waters around the islands Closer inshore they most likely support juvenile lobsters depending on the recruitment dynamics [133]. The structural complexity of seafan habitats makes them ideal refuges for fish, including commercially important species such as snappers and groupers.

1.2. DIVE TOURISM:

Seafan habitats have a high aesthetic value because they attract a variety of wildlife and are therefore an important asset to the developing dive tourism industry on the islands.

2. POTENTIAL LOCAL VALUE OF THE CORN ISLANDS' SEAFAN HABITATS

2.1. AQUARIUM AND CURIO TRADE:

Some seafan species have been harvested in other parts of the Caribbean and are exported for the Aquarium trade or dried and sold as curios. It is not known if this happens on the Corn Islands but note should be made of the potential threats of this activity.

2.2. COLLECTION FOR BIOMEDICAL RESEARCH:

Some species of seafan have been identified as important in the production of biomedically active compounds. Prostaglandins for example are among the most potent biological materials known and were a major discovery from a western Atlantic gorgonian *Plexaura homomalla* [136, 137].

3. THREATS TO THE CORN ISLANDS' SEAFAN HABITATS

3.1. MECHANICAL DAMAGE:

Seafans are very susceptible to mechanical damage and studies show that they have very slow growth rates [138]. This means that they take a long time to recover from damage. Lobster and fish traps, dredging, trawling and anchor damage are all therefore threats to these habitats.

3.2. POLLUTION:

Sewage pollution can affect seafans, either directly or through enhancement of the growth of competing macro algae. There is no centralized waste treatment plant on the Corn Islands and it possible that the near shore areas are affected by nutrient enrichment from human waste. This may be affecting the near shore seafan areas from runoff of via fissures in the islands geology [60, 86]. There is also the threat of mechanical damage and smothering by domestic solid waste as a result of offshore dumping.

3.3. DISEASE:

Mass mortalties of gorgonian seafans due to disease were recorded throughout the Caribbean in the 1980's [139].

4. POTENTIAL THREATS TO THE CORN ISLANDS' SEAFAN HABITATS

4.1. INTENSIVE COLLECTION:

Given their slow growth rates, intensive collection of seafans for the aquarium / curio industry or for biomedically active compounds is unsustainable.

4.2. BIOMEDICAL RESEARCH:

In the case of the gorgonian *Plexura homomalla* however, it was possible to isolate and artificially produce Prostaglandins and intensive collection is not required, limited collection of species for biomedical research is therefore a much lesser threat. In order for there to be an equitable distribution of the benefits of marine biodiversity resources however, there needs to be an adequate legal framework, otherwise there is a risk of biopiracy where benefits are extracted by outside operations [131].

5. RECOMMENDATIONS FOR RESEARCH, MANAGEMENT AND POLICY

5.1. DESK BASED RESEARCH:

- Investigate the importance of seafan habitats in the lobster life cycle. Assess their vulnerability to pollution and their value as a genetic resource.
- Investigate solid and liquid waste management options for the Corn Islands and carry out an ecological-economic appraisal to assess these options.

5.2. FIELD RESEARCH:

- Study the threat from mechanical impacts and investigate mitigation measures such as buoying systems and marked navigation routes.
- Monitor the status of seafan habitats surrounding the islands and any threats posed by marine pollution.
- Assessment the proportion of juvenile and adult lobsters found surrounding the islands to verify whether seafan habitats are an important habitat for juvenile lobster.
- Investigate the islands marine biodiversity to assess their potential for biomedical research.

5.3. POLICY RECOMMENDATIONS:

- Prohibit the harvest or possession of sea fans and gorgonians (octocorals), live or dead, except for legally permitted research, education and restoration programs.
- Require an environmental impact assessment for any proposed collection of seafans and in the event of collection for biomedical research, establish an equitable bio-prospecting agreement which directly benefits the conservation of the islands environment and biodiversity.
- Prohibit trap fishing within inshore seafan areas to prevent any mechanical damage caused by traps to this habitat.

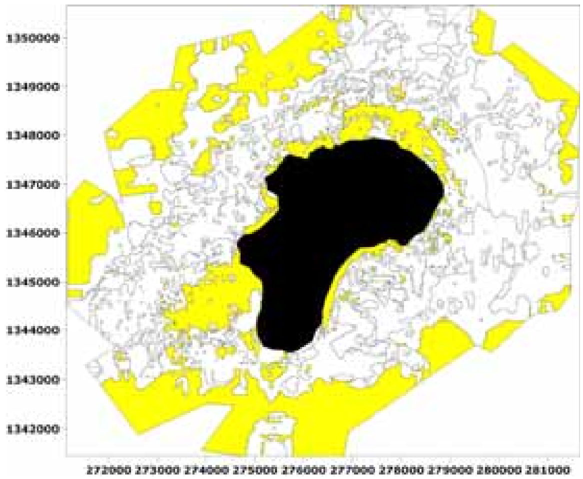
ASSESSMENT OF THE CORN ISLANDS' SAND HABITATS

Author: Duncan Hume, duncan@reefmap.org.uk

SAND HABITAT

Figure 1. Example of a Sand Habitat on Corn Island

GREAT CORN ISLAND



LITTLE CORN ISLAND

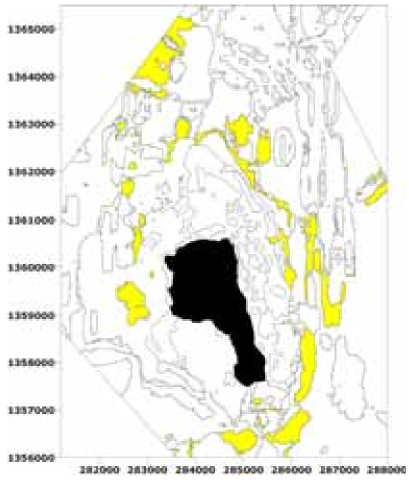


Figure 1. The predicted distribution of Sand Habitats around Great Corn Island and Little Corn Island based on Landsat TM Satellite and RoxAnn AGDS (acoustic) remote sensing surveys.

Accuracy Note: Due to overlap in the acoustic signatures used in the RoxAnn classification around both islands, there is a high chance that sand may have been misclassified as sand and algae habitat (and vice versa) in deep water areas (>12m). There was very little overlap in spectral signatures used in the Landsat classification so there is a much higher confidence in the shallow water classification (<12m).

1. LOCAL VALUE OF THE CORN ISLANDS' OF SAND HABITATS

1.1. LOBSTER FISHING AREAS:

When lobster traps are placed on areas of sand, they create an artificial habitat, which attracts lobsters.

2. POTENTIAL USES OF SAND HABITATS AROUND THE CORN ISLANDS

2.1. ARTIFICIAL REEFS:

Artificial reefs can be used to enhance fisheries production by providing new habitat for fish and lobsters. Artificial reefs can cause damage to productive seabed areas and therefore the ideal situation would be to construct them in bare seabed areas (ideal areas for reef construction are bedrock covered with sand [140]).

Artificial reefs can be used to enhance recreational and commercial fishing, provide interesting features for dive tourism or they can be used as marine sanctuaries to assist precautionary management. If they are designed correctly and constructed with the right materials they can also enhance natural reefs by provide substrate for recruitment of corals enhancing coastal defences in areas that have been degraded by human and natural impacts. There is the potential of developing a system of ownership rights which could be attributed to artificial reefs to promote stewardship of these resources and if construction and monitoring is undertaken by community members, artificial reefs could be an excellent vehicle for environmental awareness and education about the importance of marine habitats to the islands economy.

2.2. SEAWEED FARMING:

Farming of seaweeds such as *Euchema spp and Culerpa spp.* have the potential to provide alternative livelihoods on the Corn Islands and the industry is potentially well suited to the extensive, sheltered and shallow areas of sand on the South West of Corn Island. Seaweed aquaculture for the production of carrageenan, agar and alginate for export food markets (and possibly for domestic markets) is a rapidly growing industry and production is currently being tested in other parts of the Caribbean [141]. Seaweed farming is a low cost / low tech. activity and may therefore provide a livelihoods option for poorer members of the Corn Islands population although export and processing would require greater levels of investment.

3. THREATS ASSOCIATED WITH POTENTIAL USES OF SAND HABITATS

3.1. ARTIFICIAL REEFS: PRODUCTION VS. AGGREGATION DEBATE:

There is an ongoing debate about whether artificial reefs actually increase the abundance of fish (and lobsters) or just aggregate them. If artificial reefs are used by fishers, they could make the fish & lobsters easier to catch and therefore help to deplete the stocks. However, there is also an argument that they may increase production and remove the threat of habitat destruction from fishing pressure on natural reefs. If the intention is to use the reefs as a marine sanctuary to enhance the survival rates of juvenile fish or lobsters this aggregation/production argument is not a problem and they can used simply as a form fisheries management insurance. This would be an ideal use for artificial reef structures on the Islands as they can be constructed in areas where they can be easily monitored and patrolled from land.

3.2. SEAWEED FARMING: INVASIVE SPECIES:

Seaweed farming may involve the introduction of commercial strains of algae that grow with higher production rates. If these species do not exist locally, there is a potential threat of invasive behaviour that may damage the local ecology [142]. If the islands algae habitats are important as a lobster nursery habitat, invasive species may represent a significant threat through competition.

3.3. SEAWEED FARMING: DAMAGE TO EXISTING BENTHOS:

Limitations in the classification and accuracy of the habitat map mean that individual colonies or isolated coral reefs may have been overlooked; any development plans should consider this and require a detailed and accurate survey of the benthic habitats. Seaweed farming on reefs or algal habitats can have a direct impact on the substrate through mechanical damage or shading and refuse from farms may smother adjacent marine habitats [142]. It has also been suggested that herbivorous fish may be diverted from adjacent reefs increasing the risk of algal overgrowth and phase shift [143] and there is an urgent need for further research to verify the environmental impacts [142].

4. RECOMMENDATIONS FOR RESEARCH, MANAGEMENT AND POLICY

4.1. ARTIFICIAL REEF STUDY:

► Carry out an extensive literature review of artificial reef materials, construction techniques and baseline environmental requirements as well as a cost-benefit study of artificial reefs and their use in marine resource management.

4.1.1. FIELD RESEARCH:

► Undertake a detailed environmental and social impact survey to develop a rationale for the participatory construction of artificial reefs based on stakeholder perceptions.

4.1.2. CONSTRUCTION PLAN:

- ► Develop a detailed design and funding proposal for the participatory construction and post construction-monitoring of artificial reefs on the Corn Islands including an educational programme for the islands community based around the importance of the islands habitats.

4.1.3. POLICY RECOMMENDATIONS:

- ► Require an environmental impact assessment for any proposed artificial reef development.
- ► Prohibit the use of any materials that are deemed to be environmentally damaging and ensure that all materials are cleaned of any pollutants before permitting their use.

4.2. SEAWEED FARMING STUDY:

- ► Undertake a literature review and assessment of the potential of Seaweed farming on the Corn Islands as an alternative livelihood activity. Review case studies of other areas in the Caribbean to estimate the risk of invasive species.
- ► Undertake a careful assessment of potential environmental and social-economic costs and benefits to determine policy and management requirements of any proposed aquaculture projects.

4.2.1. POLICY RECOMMENDATIONS:

Require an environmental impact assessment including detailed benthic habitat mapping for any proposed aquaculture or artificial reef development activities.

ASSESSMENT OF THE CORN ISLANDS' SEAGRASS HABITATS

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SEAGRASS HABITAT

Image 1. Example of seagrass habitat.

Figure 1. Predicted distribution of seagrass habitats around the Corn Islands based on supervised classifications of Landsat TM and RoxAnn AGDS imagery

Accuracy Note: Due to overlap in the acoustic signatures used in the RoxAnn classification in deep water areas (>12m) around both islands, there is a possibility that some of the seagrass areas are infact rubble, algae and seafan habitat which may has been misclassified. This was also a problem with the optical signatures for the Landsat Classification on Great Corn. A contextual editing rule was used to deal with this ambiguity but some habitats may still be incorrectly classified and an accuracy assessment is advisable.

1. LOCAL VALUE OF CORN ISLANDS SEAGRASS HABITATS

1.1. LOBSTER HABITAT:

Seagrasses are an important habitat for the juvenile Spiny Lobster, especially in sheltered inshore areas [133, 144]. Seagrasses are also important feeding grounds for sub adults and adult lobsters as these ecosystems support important lobster prey species including clams, worms, crabs, and echinoderms [133].

1.2. FISH HABITAT:

Near shore seagrass beds are also important nursery habitats and feeding grounds for scalefish, many of which are commercially important species including snappers and groupers and which feed on the abundant prey that seagrass ecosystems support [145-148].

1.3. COASTAL PROTECTION:

The extensive root system in seagrasses extends both vertically and horizontally stabilizing the seabed and damping wave energy [149]. Coastal areas with degraded seagrasses ecosystems are vulnerable to intense wave action and coastal erosion from currents and storms.

1.4. GREEN TURTLE AND BOTTLENOSE DOLPHIN HABITAT:

The largest population of Green turtles in the Caribbean (*Chelonia mydas*) grazes directly on seagrasses on the Nicaraguan shelf [150]. They are a charismatic and highly threatened species that may prove an important asset to the nature-tourism industry. They are also an important source of food for local consumption and 11,000 are harvested on the coast each year [151]. Another charismatic mammal that is often seen around the Corn Islands is the bottlenose dolphin (*Tursiops truncates)*. They are known to feed primarily on species supported seagrass and reef habitats [152]. The availability of prey may be attracting dolphins to the islands.

1.5. WATER QUALITY:

Seagrasses help trap fine sediments and particles that are suspended in the water column, which increases water clarity [153]. Seagrasses also work to filter nutrients that come from land-based sources [143, 154]. They are highly productive ecosystems and by cycling nutrients, they preventing them from washing out to sea and therefore act as buffer against nutrient enrichment of near shore reef habitats.

2. THREATS TO THE SEAGRASS HABITATS AROUND THE CORN ISLANDS

2.1. SEDIMENTATION:

Although the Corn Islands are not affected by mainland sedimentation, local erosion impacts from land use change on the islands can result in smothering of seagrass beds, especially during the rainy season when runoff is high [97, 135].

2.2. SHADING:

Seagrasses rely on photosynthesis and therefore any obstruction that results in shading of over a long period will result in mortality. Lobster traps may cause shading of seagrasses if they are left in the same location for long periods) [100].

2.3. MECHANICAL DAMAGE:

Lobster traps may cause mechanical damage to seagrass habitat due to friction of with the seabed (if caught by currents). Propeller scarring has also been noted as a threat to seagrass habitats in other parts of the Caribbean [155]. Although such impacts may be small and isolated, they are often long lived and because seagrass beds are susceptible to 'blowouts', where small areas of mortality often result in a much larger areas being eroded due to physical and biological influences [156].

2.4. REMOVAL FOR AESTHETIC IMPROVEMENT:

In other parts of the world there have been documented cases of seagrasses being removed to create a more aesthetically pleasing environment for tourists [157]. It is not known if this has occurred on the Corn Islands but it is a potential threat.

2.5. POLLUTION:

Nutrient loading because of sewage discharge, agricultural runoff or industrial waste (e.g.: from fisheries processing activities) can lead to increased growth of macro algae, plankton and epiphytes which compete with seagrasses for light. On the Corn islands, a lack of centralised waste treatment, increasing coastal development and increasingly stressed wetland sewage treatment capability as well as waste oil pollution & effluent from fisheries processing pose some of the greatest nutrient pollution threats to near shore seagrass beds. Other forms of pollution that also affect seagrasses include heavy metals from landfill and solid waste dumps, pesticides and organic chemicals. These are difficult to measure and are often masked by nutrient overloading.

2.6. DISEASE:

Pollution has also been known to interact with a disease called 'wasting disease' which lead to the rapid die-off of eelgrass beds in the North Atlantic [158].

3. RECOMMENDATIONS FOR RESEARCH, MANAGEMENT AND POLICY

3.1. DESK BASED STUDY:

- Undertake a literature review of the importance of seagrass habitats in supporting fisheries resources and for coastal protection.

3.2. MECHANICAL DAMAGE:

- Mitigate the threat of propeller scarring and anchor damage by carrying out a study of this threat establishing navigation routes and educating fishers and other boat users.

3.3. NURSERY HABITAT:

- Study the local importance of inshore seagrass areas as nursery habitats for commercial species of fish and lobster using larval traps.

3.4. LOBSTER TRAP IMPACT STUDY:

- Investigate the impact of lobster traps on seagrass habitat to assess how long it takes mortality to occur and determine how the threat can be minimized. Consider the prohibition of lobster traps on near shore seagrass habitats.

3.5. EROSION AND SEDIMENTATION:

- Any marine dredging or coastal construction or land use changes should be required to assess the risk of erosion and sedimentation and undertake those activities in a way that minimizes or mitigates the risk to near shore seagrass habitats.

3.6. DIVE & NATURE BASED ECO-TOURISM:

- Prohibit the removal of seagrass from coastal areas for aesthetic purposes, it reduces the resilience of the islands coastline to erosion during storms and in the long term is a threat to the tourism industry.
- Undertake a survey of turtle and dolphin sightings and captures of green turtles around the islands.
- Undertake marine surveys in key sighting areas to assess the feeding habitats and species of dolphins around the islands.
- Carry out a perception study of local fishers and tourist operators to establish the perceived importance of turtles and dolphins.

3.7. POLLUTION:

- Establish a water quality monitoring programme of the island's wetlands to indirectly estimate the threat to the islands marine environment through runoff during the rainy season.
- Indirectly measure the effects of potential nutrient enrichment by monitoring algal/seagrass abundances & densities in near shore coastal waters.

ASSESSMENT OF THE CORN ISLANDS' WETLAND HABITATS

Author: Duncan Hume, duncan@reefmap.org.uk

WETLAND HABITAT

Image 1. A typical wetland on Great Corn Island

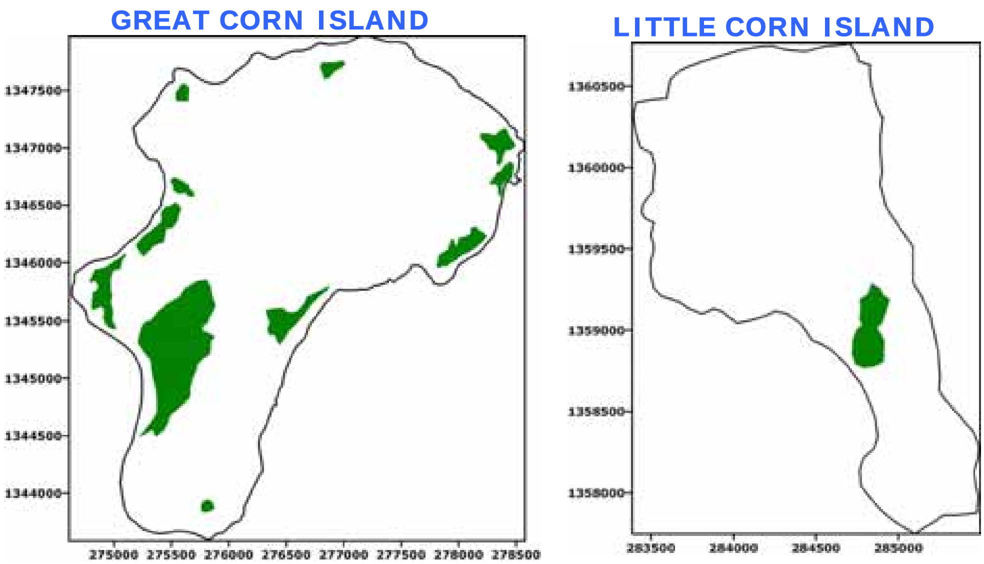

Figure 1. Spatial Distribution of the islands wetlands [3].

1. VALUE OF THE CORN ISLANDS' WETLAND HABITATS

1.1. WATER PURIFICATION & GROUNDWATER RECHARGE:

The Corn Islands do not have any centralised wastewater treatment and the wetlands are therefore of critical importance in maintaining the islands fresh water supplies which would otherwise be heavily polluted.

Wetland vegetation absorbs nitrates and phosphates from wastewater & agricultural runoff and from groundwater seepage of human waste from pit latrines. These provide nutrient input and are absorbed by wetland plants [159]. Wetland vegetation has the capacity to process harmful faecal coliforms from human waste and some species can absorb very high levels of toxic heavy metals that may leach from solid waste sources. In many countries, these properties have set a trend for the development of constructed wetlands which are used as cost effective substitutes for traditional wastewater treatment (see Kadlec 1996 for a detailed overview [160]).

1.2. COASTAL PROTECTION:

Although less that 1% of the islands wetlands are connected to the sea [63], the vegetation does offer some protection to the islands from damage during storms by absorbing wind energy and during hurricanes, from serious coastal erosion. Climate change will likely result in an increase in the prevalence of tropical storms in the Caribbean.

1.3. SEDIMENT TRAPPING:

The islands wetlands trap sediment that is washed from the islands highlands. This sediment is important in maintaining the agricultural productivity of coastal areas and by trapping sediments the wetlands prevent smothering of inshore marine habitats.

1.4. BIODIVERSITY, ECO-TOURISM AND RECREATION:

The biodiversity supported by the wetlands is an asset to the islands developing nature / eco-tourism industry. It is also likely that a variety of threatened species utilise the wetlands as habitat.

1.5. WETLAND PRODUCTS:

The wetlands on the Corn Islands support a wide variety of species of flora and fauna many of which may be utilised for subsistence by the islands poor. Potential products include shellfish, fish and firewood.

2. THREATS TO THE CORN ISLANDS' WETLAND HABITATS

2.1. NUTRIENT POLLUTION & EUTROPHICATION:

There is a limit to the ability of wetland ecosystems ability to absorb nutrients. Sources of potential contamination of Corn Island's ground water include seawater, sewage, petroleum, hydrocarbons, solid waste, non-point runoff, and fish processing waste [161].

Most wetlands are only effective in removal of about 50% of Nitrates & Phosphates and are net exporters of nutrients. Their capacity to process nutrients is highly dependant on the loading rate of sewage and wastewater entering the ecosystem [162]. With rapidly increasing population on the Corn Islands [88] and due to a lack of centralised wastewater treatment it is impossible to determine the levels of wastewater & sewage entering the islands wetland ecosystems but it is likely to be increasing.

As a result, there is a potential risk of Eutrophication of the wetlands (where nutrient enrichment results in rapid vegetative growth) which would cause anoxic conditions and ecosystem collapse. Eutrophication could have serious direct consequences for the islands freshwater supply, aquatic wildlife & birds and may threaten near shore marine ecosystems with high increases in levels of toxins, sediment and nutrients leached via through islands aquifer [60, 86].

2.2. OIL POLLUTION:

Oil pollution can block up the gas cavities in the pneumatophores or prop roots of mangroves and will cause cell suffocation due to insufficient oxygen. It also brings about high temperature on the surface of leaves of vegetation, especially when the leaves are covered with a film of dark oil [163]. Inadequate disposal of waste oil and spills from fuel storage cells are the most likely sources of oil pollution in the islands wetlands.

2.3. SEA LEVEL RISE AND SALINE INTRUSION:

According to Ruden [164] approximately one half of Great Corn Island is less than 2m above sea level and a rise of 0.5m is predicted to result in inundation of one third of the island [60]. The sea level in the Caribbean is predicted to rise by to at least that level by the end of the century [115], and this will have serious consequences for the Corn Islands. Most of the islands wetlands are fresh water. Sea level rise could result in inundation of these wetlands with sea water and this would have a significant influence on the ecological structure of these systems. Fresh water species of vegetation may no longer be able to tolerate the saline conditions and the ecosystem vegetation will either adapt with an ecological shift in species composition or decline [116]. The coastal mangrove swamps which are currently inundated periodically may also suffer further saline stress as inundation becomes more frequent. As with the freshwater wetlands, the response of the various species within the coastal wetlands is however difficult to assess without further investigation as it is dependant on a number of physiographical, ecological and biological factors [165-167]. It is however likely that sea water inundation of the islands wetlands would cause saline intrusion into the islands fresh water aquifer and result in contamination of the islands drinking supply. Inundation is far more likely if the island reefs and seagrass areas which currently protect the islands coastline from storm impacts and erosion.

2.4. DEVELOPMENT ENCROACHMENT:

The islands wetlands are protected by legislation that prevents construction within 5m of any wetland area. Without a detailed and accurate survey of the location of the islands wetlands, this is difficult to enforce and wetland degradation from physical damage or pollution may lead to a gradual erosion of these areas.

3. RECOMMENDATIONS FOR RESEARCH, MONITORING AND MANAGEMENT

3.1. DESK STUDY:

- Investigate appropriate / alternative technologies that can be used to reduce solid and liquid waste at the household level focusing on other examples of waste management in tropical developing countries.
- Investigate replanting and restoration techniques and develop guidelines for community replanting schemes.

3.2. PARTICIPATORY POLLUTION & BIODIVERSITY MONITORING:

- Accurately map the extent of the wetlands from aerial photographs or by direct mapping (GPS). Identify which areas have the highest human threats and have been degraded and target education, awareness and participatory research activities at populations in these areas.
- Survey the plant species composition and ecology of each wetland and investigate the ability of these species to deal with various pollutants and changes in salinity (including a desk study) so as to determine the resistance of different species providing possible mitigation measures in the face of environmental changes.
- Design a pollution monitoring strategy measuring levels of nutrients (N & P), salinity, PH, temperature, faecal coliforms, dissolved oxygen, hydrocarbons and volatile organic compounds and identify any point sources of pollutants.
- Survey the wildlife of the wetlands and identify threatened or endangered species or habitats that need specific protection.

3.3. EDUCATION AND ACTION:

- Develop a technical guide to the wetland & the threats they face and education materials on the importance of the islands swamps to the islands fresh water & to coastal ecosystems.
- Reduce the sources of sewage, solid waste and waste water by educating the community in the construction and use of appropriate technologies such as ‘composting earth closets’ and bio-converter systems that can deal with household sources waste in situ.
- Cleanup of any solid waste & oil pollution & rehabilitate and replant degraded wetland areas with the involvement of schools and the local community.

3.4. POLICY & MANAGEMENT RECOMMENDATIONS:

- Consider the public health consequences of allowing leachate runoff from the islands landfill and wastewater from domestic sewage to infiltrate the islands wetlands.
- Develop a waste management strategy for the reduction of point and diffuse sources of waste that may enter the groundwater and seep into the wetlands.

- Carry out technical and economic feasibility studies regarding the possibility of building a sewerage system and centralised waste water treatment plant to process the islands industrial (fisheries) and domestic wastewater before it enters the wetlands.
- Require all new coastal tourism developments to have provisions for waste water treatment.
- Strictly enforce legislation to protect the swamps from development encroachment or sources of pollution.
- Develop a contingency action plan for the cleanup of wetlands in the event of Eutrophication or pollution event of any of the wetlands.
- Consider the establishment of strict protected areas and associated eco-tourism activities related to the wetlands biodiversity.

CHAPTER 3: ENVIRONMENTAL QUALITY

CHAPTER 3: SECTION A: WETLAND WATER QUALITY

The Use of Water Quality Data and Public Perception Study as an Integrated Approach to Coastal Pollution Management

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(Illustrations by Duncan Hume)

ABSTRACT

The integration of water quality monitoring and perception studies can become an important tool for effective pollution management. This paper presents a wetland water quality survey and public perception study undertaken in Great Corn Island, Nicaragua and its implication for coastal pollution management in the municipality. Public perceptions of wetland and coastal water quality were elicited by questionnaire and un-structured interviews while water quality monitoring was conducted with the assistance of community members. The two data sets were then compared to assess whether the public perceptions are compatible with a scientific assessment of water quality. The results provide information on the contribution of public perception studies in enhancing future pollution prevention and management schemes and demonstrate the value of integrating water quality data and public perception. They also demonstrate the value of training local people to conduct water quality monitoring in order to ensure community participation, a significant element in successful management.

1. INTRODUCTION

Coastal zones are heavily dependent on the quality of their water in terms of both their ecology and economy. In relation to tourism the presence of water disease-causing pathogens, water column turbidity (as influenced by suspended solids and algae), aesthetic appearance and smell are issues of concern [168, 169]. Discharge of untreated sewage is not only a potential threat for public health and aesthetic enjoyment; it may also produce a long-term adverse impact on the ecology of critical coastal ecosystems due to the contribution of nutrients and other pollutants [169].

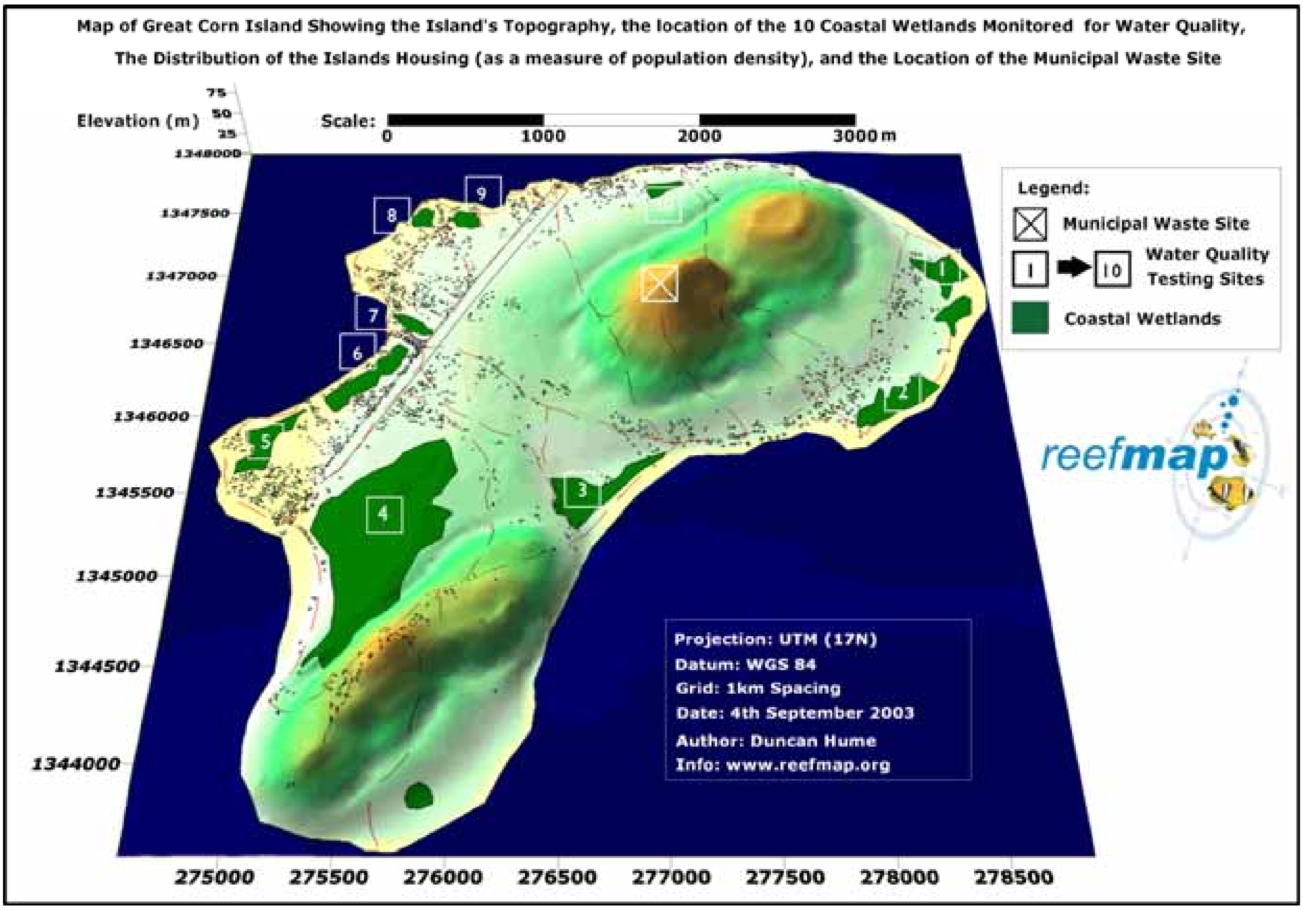

Figure 1. Great Corn Island Wetland Water Quality Monitoring Sites and Island Topography.

It has been suggested that the issue of water quality is multidimensional and goes beyond economic, ecological and health issues, encompassing the realm of social sciences [170, 171]. Pollution is not merely a physical, scientific or technical problem to solve, it also possesses social dimension that must be addressed [170, 172-174]. Individuals are the catalysts of pollution; they possess the ability to affect environmental quality through their behaviours and attitudes, which are in turn shaped by the way they perceived their environment. Perceptions studies, the gauging of an individual's perception of the environment, address environmental problems at the perceptual and attitudinal levels [170] and should be integrated in the decision making process for effective environmental management. In this context, the use of water quality perception studies to determine the cause, extent and effect of coastal pollution combined with physical monitoring appears necessary for sound pollution management.

In Great Corn Island, Nicaragua (Fig. 1), the problem of coastal pollution (especially related to wetlands) poses a serious challenge to managers. The island has a population of >7000 people divided into five administrative districts [17, 85]. The population density of approximately 600km^{-2} is one of the highest in the Caribbean [17]. The municipal and central government are now actively promoting tourism in the region in order to diversify the island economy and decrease its reliance on the fishery industry in light of the decreasing lobster stocks. With an annual population growth estimated at 3.9% and significant seasonal population movement [17], the development of tourism will inevitably bring additional demographic pressure. Population growth has already led to increased urbanisation on the island, especially in the Brig Bay area on the western side of the island, where 65% of the population is located [17]. Some scholars argue that near shore corals could be affected by subterranean discharges of sewage-contaminated groundwater originating from the island [86, 164, 175, 176].

The wetlands also suffer from development pressure and are being used as dumpsites for domestic waste [97, 177]. Increased urbanisation may be resulting in a decrease in water quality but there is currently no data available to quantify the extent of pollution and the lack of resources limits the local government's capacity to tackle the problem. In order to determine how effective pollution management in Corn Island could become a reality, a study was carried out by the author with the assistance of the local university and an environmental non-governmental organisation. The main aims of the study were: (1) to establish a water quality pilot monitoring project, where data related to wetland water quality, such as temperature, salinity, turbidity, dissolved oxygen, pH, nitrogen, are collected and used to establish a base line pollution level; (2) to determine the public perception of wetland and coastal marine pollution and their possible causes and to assess how local people foresee possible interventions aimed at reducing the impact of pollution on these ecosystems; (3) to assess whether the public perceptions are consistent with the empirical data on water quality, and (4) what are the implications for pollution and coastal management.

2. METHODS

2.1. WATER QUALITY SURVEY

Surface waters (<25 cm depth) were sampled in 10 wetlands (Fig. 1) during the start of the rainy season, between May 24th and June 19th 2003. Water temperature was determined in-situ with a handheld thermometer while environmental details of the sampling locations, including vegetation, land use and water colour, were recorded. Water samples were stored for the analysis of dissolved oxygen (DO), salinity, pH, nitrate, phosphate and turbidity. Salinity (conductivity) was measured using a refractometer. Nitrate and phosphate (ppm), turbidity (Jackson turbidity units, JTU), dissolved oxygen (ppm) and pH were measured with LaMotte test kits.

The LaMotte test kits were used following the 'Green advanced monitoring kit' and the 'Green standard monitoring kit' guidelines [178]. These are used in the United States for community monitoring and environmental education programmes for schools. Despite their relative poor precision and low accuracy as compared to more sophisticated equipment, these techniques were favoured primarily because of ease of use in remote field locations and for their low cost and user friendly approach. This ensures that future monitoring can be undertaken by members of the community with limited background and training in science.

2.2. PERCEPTION STUDY

The study area was divided into five zones reflecting the five administrative divisions of the island. Due to the majority of the population residing in Brig Bay, sampling efforts were concentrated in that neighbourhood. In each zones respondents of a minimum age of 15 years old were interviewed through a random household survey. Pilot work, while permitting correction and improvements of the questionnaires, revealed that the 15 to 25 years old age group was harder to reach through a household survey, often being absent. To ensure access to the younger section of the population four focus groups were organized with students from the two island's High Schools. The pilot work also allowed the training of four students from the Bluefields Indian and Caribbean University (BICU). The survey was conducted in both English and Spanish with their assistance.

A total of 106 structured face-to-face interviews were performed with open and close-ended questions designed to assess the respondent knowledge and perception of water pollution. Additionally, 15 un-structured interviews with community leaders (workers from NGOs, church leaders etc) as well as government representatives were carried out to gain further knowledge of the Corn Island environmental situation and ensure a process of triangulation of the survey answers.

3. RESULTS

3.1. WATER QUALITY SURVEY

This is the first water quality survey of the island's wetlands, the data representing a considerable increase in quantitative information and a baseline for future studies. Rainfall and tidal activity associated with the rainy season might have influenced water quantity and quality. Nevertheless, the data reveals that wetlands located on the western side of Great Corn Island presented a lesser water quality. Distinct patterns seen in environmental variables are discussed below.

3.2. NUTRIENTS

Phosphate concentrations were typically higher in all sample locations compared to the UNEP 1 mg/L (approximately 1 ppm) standard in nutrient sensitive tropical waters like wetlands [179]. The highest concentrations (>3ppm) were observed in sites located on the western side of the island (table 1). The visual observation and water colour suggested that most of these sites had been recently contaminated with sewage or detergents. For nitrogen, a large proportion of the samples gave values below the detection limits of the field site analysis system (Table 1).

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Phosphate ppm	1.0 - 2.5	1.0 - 3.0	2.0 - 3.0	3.0 - 4.0	2.0 - 4.0	3.0 - 4.0	4	1.0 - 3.0	2.5 - 4.0	2
Nitrogen ppm	<0.25 - 1.0	<0.25	<0.25– 2.0	<0.25	<0.25	<0.25	<0.25 - 2.0	<0.25	<0.25	<0.25

Table 1. Nitrate and Phosphate Concentrations recorded at Monitoring Sites.

The low values for N can be expected in tropical wetlands systems [180], and substantiate the hypothesis that most inorganic phosphorous is retained in wetlands while there is a tendency for negative retention of nitrates probably due to the export of organic matter which associates very much with nitrates [181].

3.3. SALINITY AND PH

Salinity showed a wide range of variability among sites, reflecting the type variety of wetland sampled, from lagoons to freshwater wetlands (Table 2). pH measurements ranged between 6.5 and 9.5, with site 5 obtaining the highest values. The most acidic samples were found in site 6 and 9. During the sampling events, these sites were highly enriched in dissolved humic compounds and other products of organic decomposition which could explain such as high acidity.

3.4. DISSOLVED OXYGEN PERCENT SATURATION

Dissolved oxygen percent saturation varied between sites (Table 2). A majority of sites on the western side of the island had DO percent saturations below 90% with site 9 presenting the lowest value and anoxic conditions. Pollution contributes oxygen-demanding organic matter (like sewage and agricultural runoff), or nutrients that stimulate growth of organic matter, decreasing the average DO concentrations [178]. The low percent saturation (<40%) observed at site 8 during two sampling events and the near anoxic conditions at site 9 suggest that these wetlands are subject to some sort of contamination. Site 8 is located directly behind a hotel and presents solid and organic waste on its surface while site 9 is exposed to dredging due to construction work, sustaining this hypothesis. If lower oxygen concentrations are expected in the tropics than in temperate waters [182], organisms in tropical ecosystems live at level closer to their lethal limits [182]. There is a lesser margin for changes in oxygen conditions to not affect organisms and the wide variations of level of percent saturation in Corn Island wetlands could adversely affect its fauna.

Site name and number	Characteristics of the sampling site/Ecological observations	DO % Saturation	pH units	Salinity %0	Turbidity in JTU
Sally Peaches 1: Brackish/saline lagoon. Herbaceous surface vegetation and forested (*Cocolobba uvifera, Cocos nucifera, Chrisobalanus icaco*)					
A17060304*		106.33	8.25	5	0
A24050301		101.45	8	35	0
A31050345	Sample taken directly behind a house	41.1	8.5	0	0
Content Point 2: Intertidal forested wetland, dominated by white mangroves.					
B26050303		89.74	8	19	20
B26050304	Near cattle settlement	64.1	8.5	28	0
Long Bay 3: Permanent marsh; appears to have a connexion to the sea but no tidal influence during the time of sampling. Herbaceous vegetation (grasses and sedges)					
C06060301	Presence of cattle	102.56	7.5	0	0
C06060302		.	7,5	0	0
C27050301		80	8.5	0	0
C27050302		81.08	8,5	0	0
Queen Hill 4: Intertidal forested wetlands					
H02060303	*Solid waste and strong odour.*	76.92	7.5	3	0
H02060304		80	7.5	3	0
Waula Point 5: Coastal brackish/saline lagoons; herbaceous vegetation.					
E03060304		82.19	9.5	5	0
E31050301	Stagnant waters behind restaurant. Presence of solid waste and strong odour.	13.33	9	4	10
E31050302	Shallow area near shore, faint odour.	93.33	8.5	5	0
E31050303	Latrines in the vicinity and strong odour	66.67	8.5	5	10
Brig Bay 6 : Intertidal forested wetlands					
I160603	Water colour impaired (white colour indicating detergent) and stagnant water	80	7.25	0	0
I16060301	Stagnant water	77.92	7.5	0	0
I16060302		76.92	6.5	0	0
I16060304	Sample taken on the seaward side of the wetland	66.67	7.75	2	0
Brig Bay 7: Freshwater, seasonal forested wetland, located in the most densely populated areas. Forested vegetation dominated by Pterocarpus oficinale with the presence of *Achrostichum aureum.*					
D19060301	High water level, strong sulphuric odour and presence of solid watse	.	7.25	0	20
D19060302			7	0	20
D28050301	Low water level. Strong odour (sulphuric like). Water visual impairment: presence of solid waste, plastic bottles and bags. The odour was also very strong (sulphuric like).	89.74	7	0	60
Mosquito Point 8 : Intertidal forested wetlands dominated by white mangroves					
F02060301	Behind Hotel Panorama, great amount of solid and organic waste; strong odour.	83.33	8	12	0
F02060302		85.71	7.5	15	100
F17060301		36.36	7.25	4	10
F17060302		25.97	7.25	4	0
Jackson 9 : Intertidal forested wetlands dominated by white mangroves					
G17060303	Water colour black and sulphuric odour really strong.		6.5	11	90
G26050301	Distinct odour, stagnant water.	64.1	8	19	40
G26050302	Distinct odour; small oil or detergent plume and stagnant water	0	7,5	18	80
Oil Factory 10: Freshwater, seasonal forested wetland					
J19060303			7.5	0	0

Table 2. Some physical, chemical and environmental characteristics of sampled wetlands.

4. PERCEPTION SURVEY

4.1. PERCEPTION OF ENVIRONMENTAL CONDITIONS & IMPORTANCE OF POLLUTION

The first part of the questionnaires tried to establish respondent's perception of the state of their coastal environmental resources. Respondents were asked to rank the conditions of beaches, coral reefs, wetlands and coastal waters into very good (1), good (2), not good not bad (3), bad (4) and very bad (5). On average, wetlands received the lowest score, 1.94 (±0.21) while coastal waters were generally considered in good or very good state with a mean score of 3.34 (±0.29). In another question, the respondents were asked to compare wetland and coastal pollution with some other issues that have proven to be important in Great Corn Island. For the most part a majority of respondents felt that the issue of pollution was as important as crime and drugs (50.9%), fisheries (41.5%) and education (48.1%).

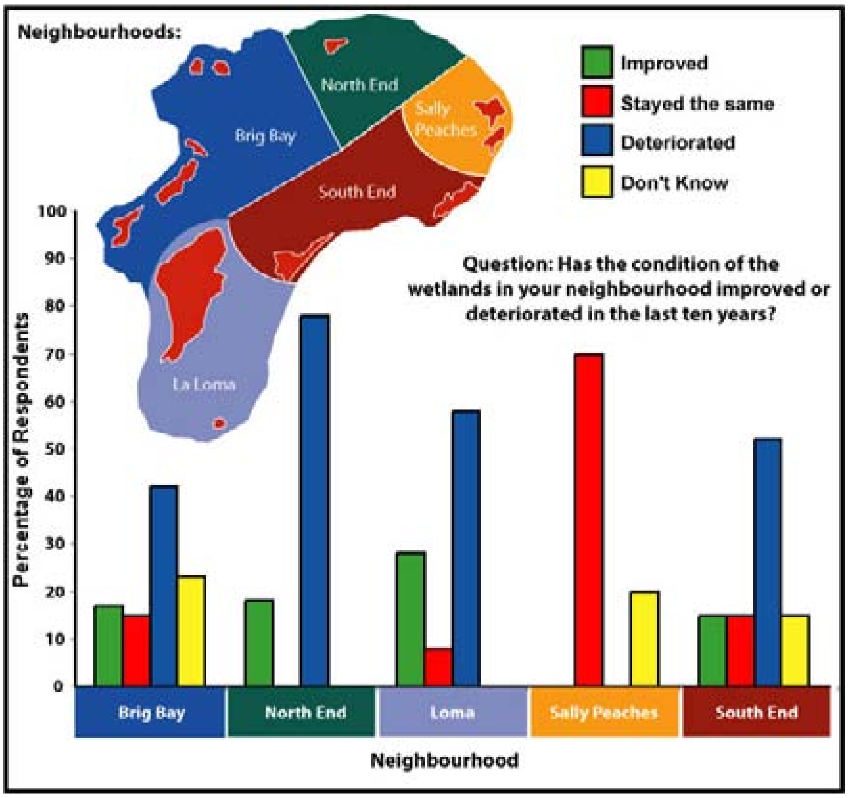

Figure 2. Perceived conditions of wetland compared to 10 years.

4.2. LOCALISATION OF POLLUTION

A section of the questionnaire was devoted to elicit residents' perception of their own neighbourhood environment. Respondents were asked whether they thought the condition of wetlands in their neighbourhood had deteriorated or improved in the last 10 years. The majority of respondents (45.7%) said that it had worsened, 17.1% said it had improved while 16.2% said it was the same. North End and Loma were the areas perceived by residents as having undergone the most negative change (Fig. 2).

The survey also tried to assess public perception of the spatial dimension of pollution. Respondents were first asked to identify among eight marine zones around the island which one(s) was the most polluted. Then the same question was asked regarding five inland areas. The western side of the island was perceived as the most affected by pollution; more than 70% of responses designated the Brig Bay area (E-F-G) and it's coastal zone (zones 8-7-6) as the most contaminated one (Fig.3). The one-to-one interview discussions explored the rationales behind the spatial perceptions identified in

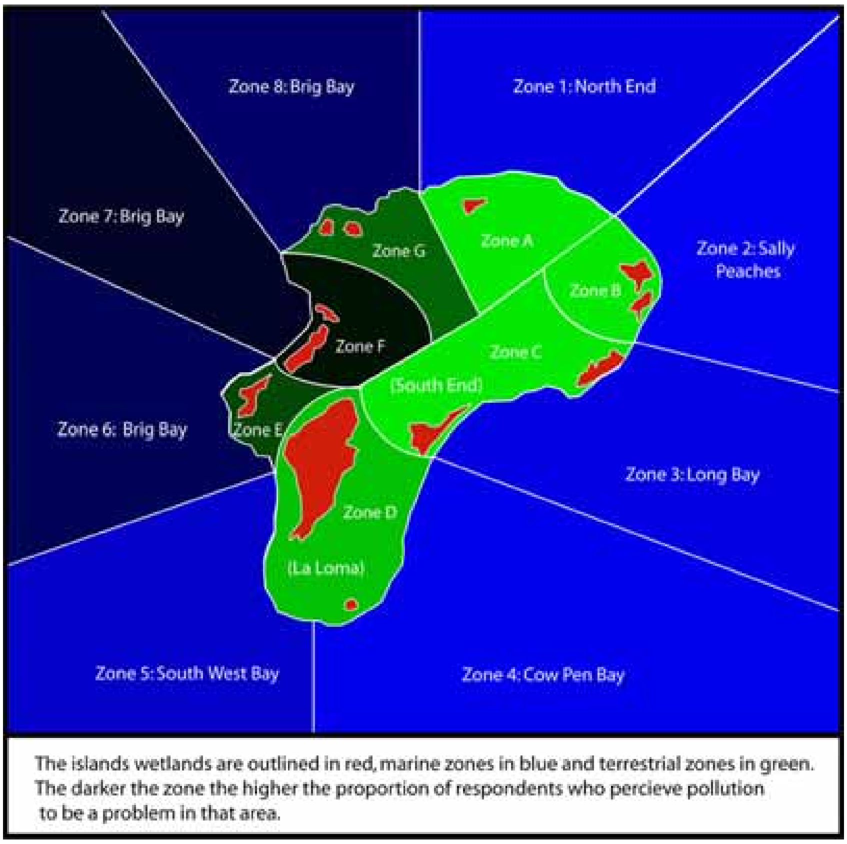

Figure 3. Perceived localisation of pollution around Corn Island.

the survey. A majority of people interviewed stated that overpopulation and lack of water treatment on the western side of the island made it the more exposed to anthropogenic pressures.

4.3. PERCEIVED CAUSES OF POLLUTION

Respondents were asked which factors might be contributing to the pollution of wetlands and coastal waters. Figure 4: shows than when asked '*What do you think are the main causes of wetlands*', the most frequently mentioned causes were garbage, sewage and dead animals. For coastal waters, hydrocarbons and solid waste were perceived as the major causes of pollution. The higher percentage of no replies in the case of coastal waters indicates the fact that the public found it difficult to identify sources of pollution in the sea, a majority of respondents unable to answer arguing that the seawater was not contaminated. This is not surprising since in the first part of the survey the condition of coastal waters was seen as good. A small amount of respondents (less than 3%) mentioned the lack of environmental education as a cause of pollution of coastal waters and wetlands, most of them arguing that people knew what steps to take to reduce pollution.

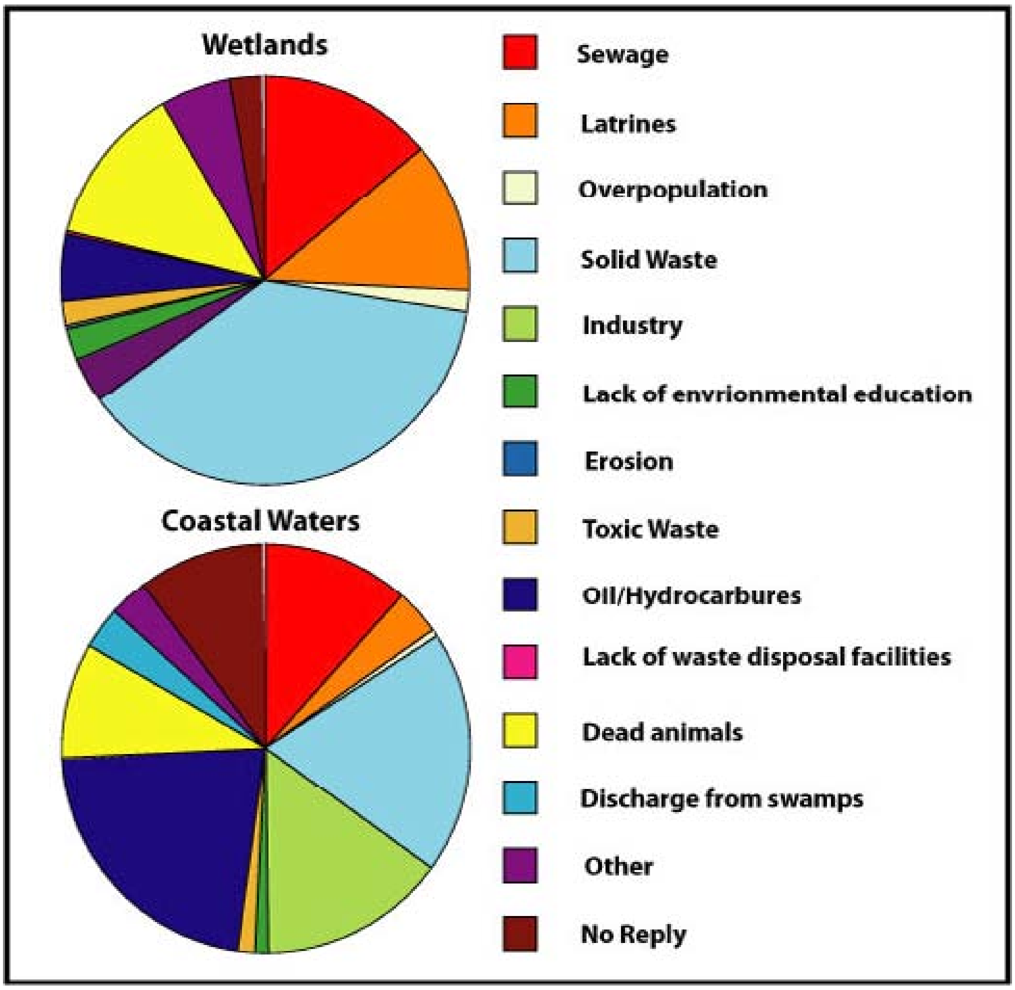

Figure 4. Causes of pollution as perceived by Corn Islanders.

5. PERCEIVED MANAGEMENT OPTIONS

When individuals were asked about their knowledge of environmental programs aimed at reducing contamination on the island 47% replied that they knew none. A few months before this study the municipality put in place a black oil recycling program to reduce the impact of hydrocarbons on the environment. However, the population does not seem to be aware of the program (only 8.5% of respondents aware of environmental programmes mentioned it, see fig.5), highlighting the need for increased information dissemination of environmental programs. Once the

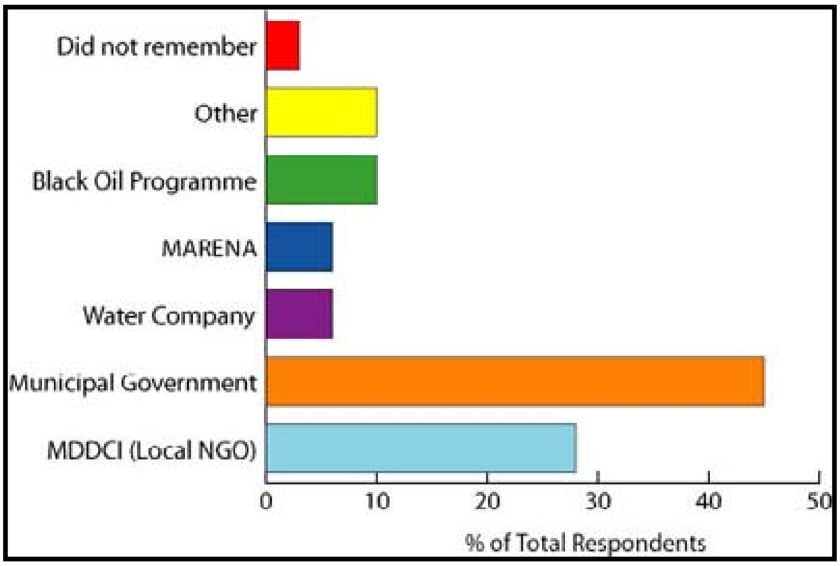

Figure 5. Programs aimed at reducing pollution.

breadth of knowledge of environmental programs was establish, the survey tried to determine which activity was perceived as effective in reducing pollution. Cleaning and education were seen as the least effective actions to reduce pollution on the island with respectively mean scores of 2.1 (±0.21) and 2.2 (±0.22). A better wastewater treatment was seen as the most effective action with a mean score of 3.1 (±0.20) while stricter laws came second with a mean score of 2.6 (±0.23). When asked if they would have time to participate in conservation activities such as cleaning the wetlands and the beaches, 76% of respondents said yes.

6. DISCUSSION

6.1. IDENTIFICATION OF POLLUTION: PERCEIVED AND ACTUAL WATER QUALITY

The literature on perception studies supports the fact that they can be a tool in environmental management and more specifically in pollution control by providing information to decisions makers [170, 173, 183, 184]. However, Coughlin [171] argues that if perception of water pollution is essential to decision-making but no relationship can be demonstrated with physical measurements, the identification of perception is of little value in itself. In the case of Great Corn Island, the wetland water quality survey identified the western side of the island as of poor to average water quality. Similarly the perception study indicated that respondents felt that Brig Bay was the area most affected by pollution. Thus, when it comes to the localisation of pollution and the identification of areas of concerns, perceptions are reasonably consistent with scientific measurements. Faulkner and House [183, 185] established that the presence of solid waste contaminants in the water played a significant role in the public's perception of water quality. Throughout the survey in Corn Island the problem of waste disposal was a recurrent issue and appears to be a significant factor in respondent's perception of water quality. Even when mentioning industrial discharge as a cause of wetland and coastal water pollution, respondents referred to it in terms of sewage and not as input of chemicals in the environment. This implies that public perception is not effective in identifying more subtle traces of pollution, for instance heavy metals or chemicals.

6.2. COMMUNITY MONITORING & PERCEPTION STUDIES: TOOLS FOR MANAGEMENT

In Nicaragua, like in many developing countries, there is lack of data about coastal water quality and coastal pollution necessary for decision making due to economic difficulties and lack of infrastructure. The water quality survey conducted in this study was the first one of its kind on Great Corn Island. The success of the pilot work in capacity-building and community participation revealed that community monitoring using low-cost user friendly techniques was the most cost effective way to provide water quality information to managers despite the low accuracy of the data. Community coastal pollution monitoring has also been proven to empower communities and build continue interest in environment issues, ensuring full participation in environmental management and problem solving [186]. The public perception survey also revealed that the residents of Corn Island were highly preoccupied by the conditions of the island's wetlands. Despite the crisis in the fishing industry due to decrease in catch sizes and increase in the crime rate related to the narcotic trade, respondents still felt that pollution of coastal environments was an important issue. In identifying priorities of concern, the perception study becomes a valuable vehicle for enhancing communication and interaction between managers and the community, offering the possibility to incorporate citizen's concerns in management planning.

Environmental education is often advocated as a tool to palliate environmental degradation [187], and in the last ten years, efforts to increase environmental education programs in schools and communities on the island have been successful [188]. This could elicit the current attitudes of respondents towards increased environmental education as an ineffective pollution management tool. Indeed the survey and the in-depth interviews revealed that a majority of residents felt that environmental education was inefficient in pollution control and actions such as the implementation of a waste water treatment system and efficient collection of garbage were more appropriate. These results do not undermine the need of more environmental education programs, rather they support their successes: the public in Great Corn Island is now sensitive to pollution issues because of efforts made in the past. In order to maintain this awareness and empower the community to bring about change, environmental education programs must be sustained. These results also underline the fact that pollution management must be addressed in a holistic manner, incorporating technological solutions (waste water treatment) and improved municipal services (better garbage collection) as well as education campaigns and community participation.

7. CONCLUSION:

The municipality of Great Corn Island needs to have an integrated approach to coastal pollution management.

- Technological solutions must be sought as revealed not only by the scientific data but also by the public perception survey.
- Environmental monitoring must be undertaken in order to provide managers information indicative of the condition of the environment The water quality survey demonstrated the value of training local people to conduct water quality monitoring and efforts must be sustained to implement long-term program with this low cost alternative.
- The social dimension of pollution must not be overlooked. Public perceptions need to be integrated in decision-making, enabling managers to incorporate the community's concerns into policy objectives and education campaigns must continue to harness communities' awareness of pollution issues.

8. ACKNOWLEDGEMENTS

I wish to thank all the Reefmap team members for their support as well as Liza Gonzales from the Nicaraguan Environmental Ministry (MARENA) and Mauricio Lacayo from the RAAN-asdi-RAAS programme in Managua. I also wish to thank Gary Archibald, Marlon Alfaro Dublón, Adalia White and E. García from the Bluefield Indigenous Caribbean University for their invaluable help with the collection of data. The project greatly benefited from the assistance and insight of Norma Dixon of the Movimiento para la Difensa y Dignidad de Corn Island. Finally my thanks go to my supervisor Dr. Rob Upstill Goddard.

CHAPTER 3: SECTION B: CORAL REEF SEDIMENT IMPACTS

Sedimentation quality change and the presence of indicator species: A study across a seaward sedimentation gradient from the Pearl Cays to the Corn Islands

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ABSTRACT

Low diversity and live coral cover are often attributed to terrigenous sediment inputs arising from deforestation and poor land management in nearby coastal catchments. The Pearl Cays region of the Atlantic coast of Nicaragua is influenced by sediment runoff with the highest total mean sedimentation rates (from traps 50cm above substrate) at the inshore sites being 3.7 $\pm$ 0.3 (S.E.) $mg.cm^2.d^{-1}$. Benthic communities and diversity patterns were studied using quantitative video sampling methods with two different data collection techniques. The site most affected by terrigenous sedimentation was found to be the most diverse with 21 species of hard coral along 5 x 25cm x 50m transects and an average total live coral cover of 26%. The inshore site showed sedimentation quality to be largely related to terrigenous influence, with offshore sites influenced mainly by reef erosion (high carbonate and organic content). Strong correlations were found between abundance of sedimentation-tolerant species of scleractinian coral such as *Solenastrea bournoni*, *Agaricia sp*, *Siderastrea radians* and the terrigenous acid insoluble non-calcareous sediment fractions. Similarly, there was a significant decrease in the ratio of *Porites astreoides* brown to green colour morphs along the decreasing gradient of terrestrial influence. From a management perspective short-term records of total sedimentation rate alone is not a good indicator of coral reef health. It is possible to conclude that a more complete approach to sedimentation studies is required, based on sedimentation quality, timing and quantity.

1. INTRODUCTION

The last few decades have seen increased awareness regarding the effects of erosion, deforestation and agriculture intensification on coastal reefs, which have highlighted the importance of coastal zone interactions and the need for a holistic integrated approach to coastal zone management. Sedimentation and eutrophication from runoff are now thought to be one of the biggest potential sources of coral reef degradation from human activities and have become a widespread problem worldwide and especially in the Caribbean [189-192].

Excessive sedimentation can adversely affect the structure and therefore function of coral reef ecosystems by altering both physical and biological processes [191]. The effects on corals depends on the degree to which the stress is from reduced light levels from high turbidity, accumulating sediment, effects on particulate food quality [191, 193], interference with feeding mechanisms or increased mucus production impacting energy budgets [194].

The inability to predict impacts of sedimentation influence at a given site is a well known problem, with many studies finding low impacts of large amounts of sedimentation [195-199]. Indeed, just as many studies have identified detrimental consequences [189, 200]. Past research aimed at trying to assess such effects of sedimentation on coral community structure however, have to a large extent been biased towards inorganics, with most experimental studies employing calcareous sediment or sediment with organics removed [190, 201-203]. Although indicating clearance rates, mortality as a result of smothering or possible effects of resuspension, such studies bear little resemblance to the sedimentation composition and characteristics faced by coral communities as a consequence of runoff. Studies determining linear extension rates found positive correlations between growth rates in *Montastrea annularis* and carbonate percentages, hence carbonate does not interfere in the growth rates of this species as it may be incorporated into the skeleton [192]. Similarly, small increases in overall ambient sedimentation were found to increase growth rates in *Siderastrea siderea* [204], and *Montastrea cavenosa* [205], probably by increasing the availability of carbon and inorganic nutrients that can be exploited by suspension feeding [203]. Looking at total sedimentation and consequences of calcareous sediment on coral responses is therefore not a good management measure when it comes to assessing runoff derived coral reef impacts. Predicting long-term coral responses to sedimentation

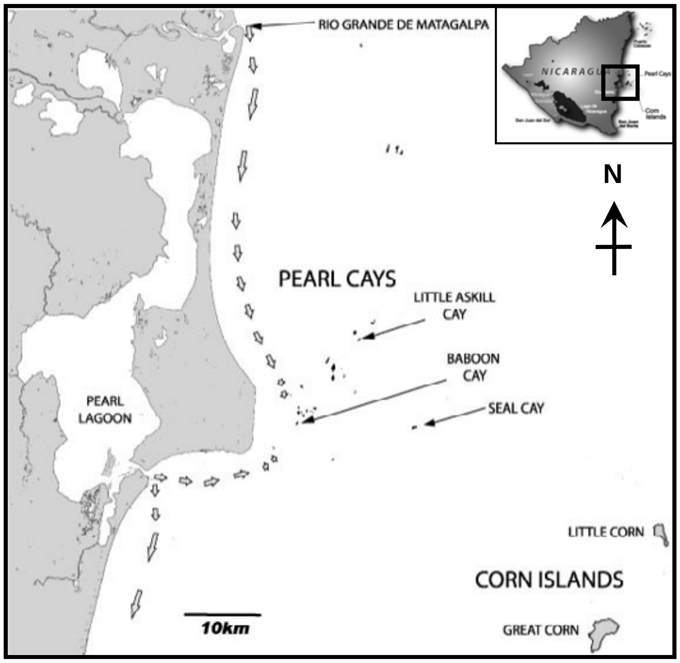

Figure 1. Map showing positioning of study sites, and arrows showing the north-south flow of the turbid boundary current created by the Rio Grande de Matagalpa, and the influence of the outflow from Pearl Lagoon.

stress will require an approach that looks at the quality and proportions of sediment constituents as well as total sedimentation rates.

Ninety percent of Nicaragua's watersheds drain towards the east coast through eleven major rivers [176]. Indeed, increased deforestation has led to high erosion along much of the watershed, which has resulted in higher sediment loads that are believed to have destroyed several of the large near-shore reef complexes on the central Nicaraguan shelf [206]. Persistent momentum provided by the northeast trade winds and density gradients set up by riverine effluents interfacing with saline shelf waters, produce a strong (over 70 $cm.sec^{-1}$) north-south flowing coastal boundary current. This creates a zone, approximately 10 km wide, with a ramp of terrigenous sediments forming an interface between the shelf and shoreline where high turbidity and shifting substrate prevent reef formation [207]. The Pearl Cays complexes of shallow reefs lie close to shore on the edge of the turbid coastal boundary created by the outflow of the Rio Grande de Matagalpa, emptying into the Caribbean north of Pearl Lagoon (Fig. 1).

The purpose of this study was to investigate the spatial differences in sedimentation quality distribution, and examine how the fractions of organics, calcium carbonates, and non-carbonates changed with distance from a terrestrial runoff source. The main aim was to establish correlations between the different sedimentation constituents collected in sediment traps, benthic cover and indicator species using video analysis.

2. MATERIALS AND METHODS

LANDSAT imagery of the Atlantic coast of Nicaragua was used to select 4 island sites in order to represent the terrigenous sedimentation gradient (Fig. 1). The sites ranged from the turbid (low visibility 4-5m) inshore waters of the Pearl Cays complexes heavily affected by the coastal turbid boundary layer, to the clearer waters on the offshore site at Little Corn Island (high visibility 30m). LANDSAT imagery indicated the northeastern aspect of the reef complexes on these cays to be the largest and most developed. For this reason, study sites where

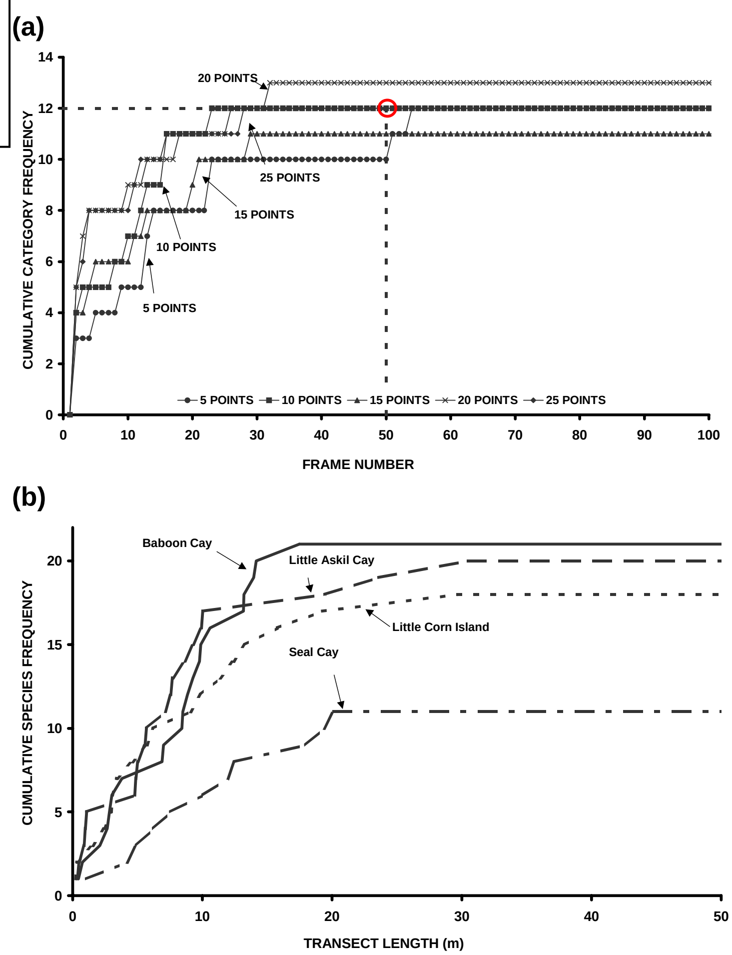

Figure 2. A) Cumulative frequency of benthic categories detected per frame with varying point counts per frame (5 to 25 points). B) Average cumulative species frequency for the coral abundance and diversity analysis.

selected on the exposed northeastern end of the cays. At each site, sediment samples were collected using 9 sediment traps in 3 arrays. Because of trap size they were set 50 cm off the substrate and haphazardly around the sites where transects were filmed and left for a 24hr period. The trap openings were 92 mm in diameter with a width to depth ratio of approximately 3:1, a good ratio for estimating vertical fluxes [208]. Water transparency (visibility) was measured using a horizontal Secchi disc within 2hrs of midday under clear sky conditions. Sediment trap samples were preserved in 0.5% formalin. On returning to the laboratory salts were initially removed by rinsing with deionised water (Milli-Q) before centrifugation and drying to constant weight at 70°C. Dried samples were placed in a desiccator with silica gel to prevent the absorption of moisture before being weighed to the nearest 0.001mg on a Mettler MT5 analytical balance. After weighing, organic portions were eliminated by combusting the samples for 2 hrs at 450°C. The same weighing procedure was carried out prior to the calcareous fractions being eliminated through repeated rinsing in a 10% HCl solution. Salts formed during the acid washing were removed by rinsing with deionised water before centrifugation and drying to a constant weight at 70°C as before. The remaining acid-insoluble fractions were weighed, after which relative proportions of organics, non-carbonates and carbonates were calculated. Organic fractions were not adjusted for formalin content.

Video transects were used to assess benthic community composition. At each site, 5 x 50m transects were selected haphazardly at a depth of 6m and recorded perpendicular to the substrate from a fixed height of 25cm and a speed of 10m.min^{-1}, producing swaths or belt transects approximately 25cm wide. To film benthic transects, a diver used a SONY DCRSC100e digital video camera in an underwater housing (Mako ™ Light & Motion Industries).

Benthic community data were collected for each transects using a point count method. A pilot study was conducted on the transect considered to have the lowest coral cover, in order to establish a minimum effective data point density for frames per transect and points per frame to distinguish benthic categories with relative accuracy. An initial complete-transect 100 frame analysis using 25 point identifications per frame gave a total of 2500 point counts for the transect. The final percentage cover estimates were used as a standard to compare the effectiveness of other sampling strategies. Ranging from 5, 10, 15, 20 and 25 points per frame and increasing frames per transect, cumulative category frequencies indicated relatively quick broad category saturation in the first 25 frames, with an increase in cumulative counts with sampling intensity. Sampling at a point density of 10 and frame number of 50 gave a good ability to detect 12 categories including coral (1.1% cover). Further analysis indicated variance had decreased sufficiently at a 50-frame 10 point cut off, and this was considered adequate for the questions and resolution required (Fig. 2a). These results compared favourably to those of Aronson & Swanson [209], who similarly concluded the appropriate sampling design was 10 points per frame and 50 frames per transect. Their findings were however for 25m transects with a frame width of 0.4m, but nonetheless the results were comparable with 1 point per 0.02m^2 and 1 per 0.025m^2 of substrate for the present study.

Cumulative species frequency analysis indicated that the point-count method was inadequate at detecting changes in hard coral diversity. For this reason a different data collection method was used, which was based on the frequency of colonies observed by species per transect (Fig. 2b). The results indicated total species saturation within 30m for all sites (Fig. 2b). With a total of 21 species detectable at Baboon Cay compared to 13 species using the point-count method.

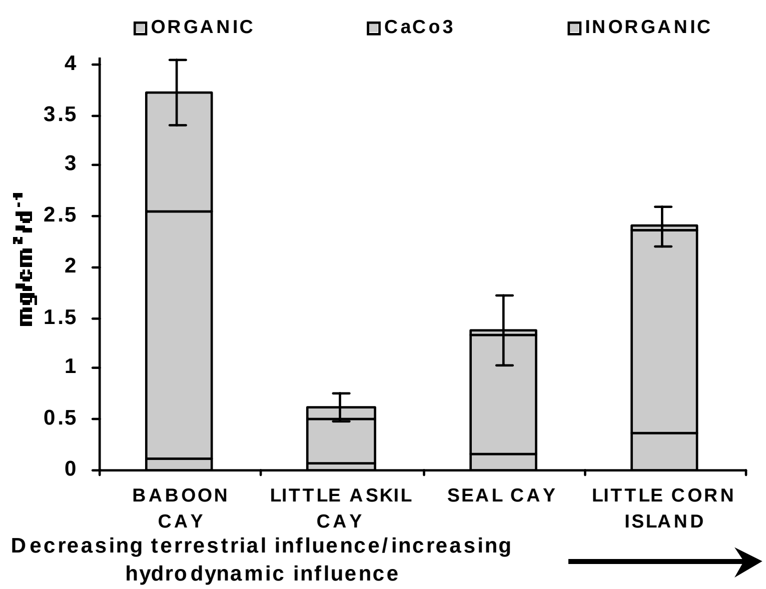

Figure 3. Sediment quantity and quality showing total sediment rates (mg.cm^2.d^{-1}) with 95% confidence interval and quantity of organic, calcium carbonate and non-carbonate fractions.

3. RESULTS

3.1. SEDIMENTATION RATE AND QUALITY

To assess the relationship of sedimentation rate between the different sites and differences in the relative proportions of sedimentation quality, a one-way ANOVA (plus multiple comparisons) and Chi-squared test were carried out. There were significant differences in total sedimentation rate between sites (one-way ANOVA, $F = 19.83$, $p < 0.001$, Fig. 3). Tukey's and Fisher's pairwise multiple comparisons indicated the only significant difference occurred between site 1 when compared to all other sites. A two-way Chi-squared test showed there were significant differences in the proportions of organic, calcium carbonate and non-carbonate sedimentation between sites ($X^{2} = 57.6$, df = 6, $p < 0.001$, Table 1). This shows that there were differences in the total sedimentation rates and relative proportions of organic, calcium carbonate and non-carbonate between sites.

Sites	Relative proportions (%)		
	Organic	Calcium carbonate	Non-carbonate
Baboon Cay	3	65	32
Little Askil	11	73	16
Seal Cay	12	86	3
Little Corn Island	16	83	1

Table 1. Sediment quality. Showing relative percentage proportions of organic, calcium carbonate and non-carbonate sediment constituents.

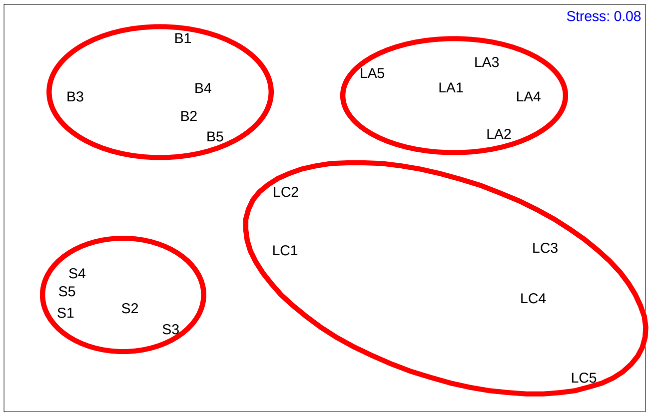

Figure 4. Multidimensional scaling ordination showing changes in benthic community composition for the 4 sites. The stress value for the ordination was 0.08, indicating the 2D distances between samples is a good representation of the multidimensional similarities. MDS based on Bray-Curtis similarities from √- transformed data for the 5 replicates at 4 sites. B = Baboon Cay, LA = Little Askil Cay, S = Seal Cay & LC = Little Corn Island.

BENTHIC COMMUNITY ANALYSIS

To assess the changes in the benthic community composition between sites multidimensional scaling (MDS) using PRIMER [210] was combined with ANOSIM, and SIMPER dissimilarity analysis. MDS analysis showing benthic community composition for the sites (Fig. 4) clearly showed the differences between sites. These changes in community structure were significantly different (ANOSIM $R = 0.82$, $p = 0.1$). SIMPER analysis showed that the highest dissimilarity in benthic group composition occurred between Little Askil Cay and Seal Cay, with fleshy upright algae contributing most of the dissimilarity. Lowest dissimilarity occurred between Baboon Cay and Seal Cay again due to the high dominance of fleshy upright algae and the relative lack of *Agaricia tenuifolia* at Seal Cay (Table 2). Measures of diversity for benthic cover using Shannon (H') and Brillouin Index (HB) showed decreasing Benthic covers of the main categories at Baboon Cay indicated an even distribution compared to other sites, with Little Askil Cay, Seal Cay and Little Corn Island being dominated by turf algae, fleshy upright algae and crustose coralline algae respectively (Fig. 5).

Location	% disimilarity	*Sp.* contributing to 45-65% between site dissimilarity
Baboon vs. L. Askil	63.81	Fleshy upright algae, Turf algae, *A. tenuifolia*
Baboon vs. Seal Cay	48.71	Fleshy upright algae, *A. tenuifolia*, Sand
Baboon vs. L. Corn	66.95	Crustose coraline algae, *A. tenufolia*, Fleshy upright algae
L. Askil vs. Seal Cay	76.34	Fleshy upright algae, Turf algae, Sand
L. Askil vs. L. Corn	55.72	Turf algae, Crustose coraline algae, Fleshy upright algae
Seal vs. L.Corn	66.38	Fleshy upright algae, Crustose coraline algae, Sand

Table 2. SIMPER analysis showing the percentage dissimilarity in benthic group composition and the three main benthic components, which together contributed 45-65% of between site dissimilarity.

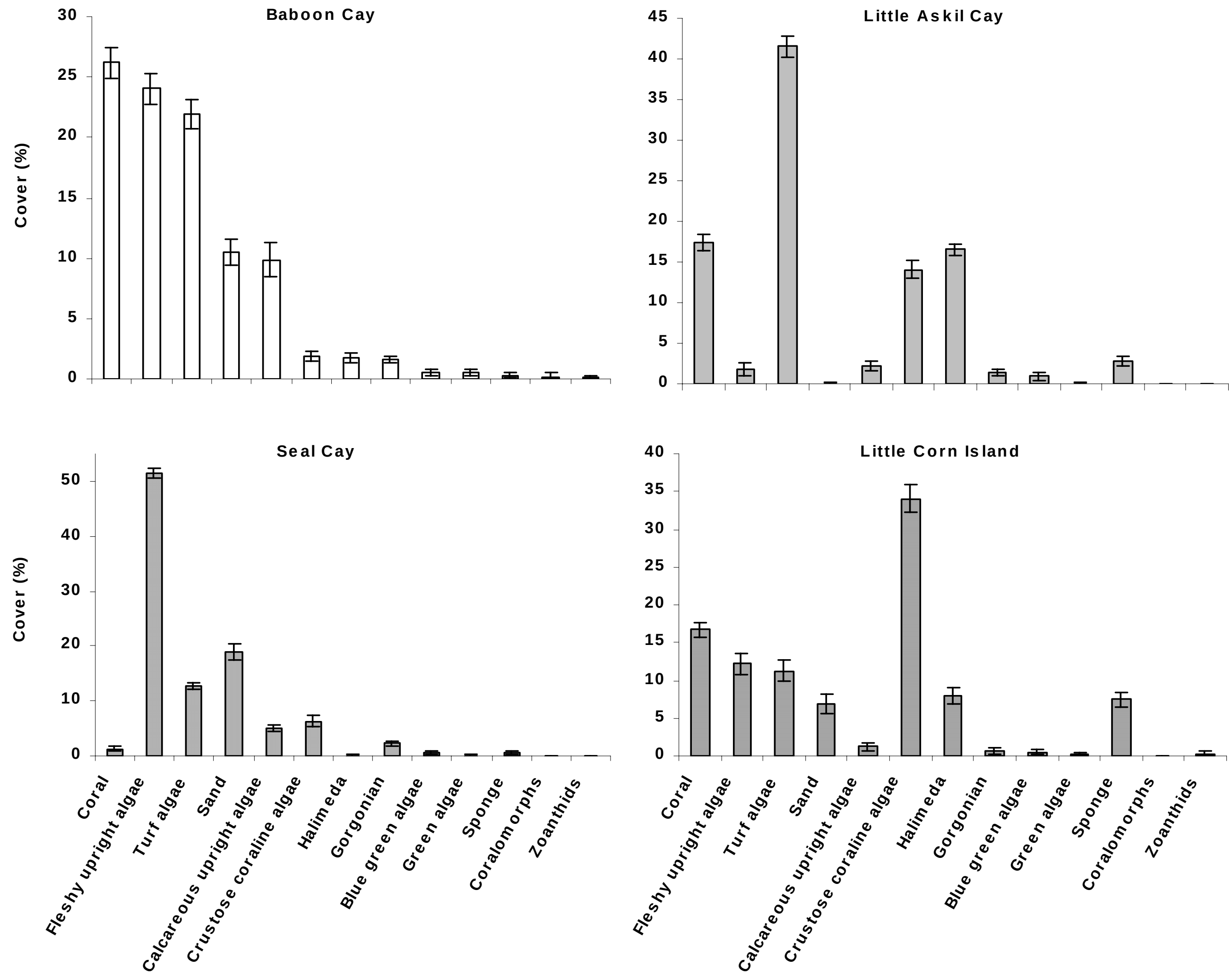

Figure 5. Mean benthic community composition at the 4 study sites (± 95% confidence intervals) showing percentage cover (%) for each of the major benthic categories. The lower x-axis categories apply to all graphs. n = 5 transects per site.

3.2. CORAL & GORGONIAN SPECIES FREQUENCY ABUNDANCE

A total of 26 species of hard coral and eight species of gorgonian were recorded from transects at the four sites using the species abundance analysis. Highest hard coral diversity (19 species) and live coral cover (26%) occurred at the site with the highest total sedimentation rate (Baboon Cay). The coral and gorgonian abundances were also analysed using MDS, which gave a stress value of 0.09 (Fig. 6). ANOSIM analyses showed significant differences in coral species composition between sites (ANOSIM R = 0.76, p = 0.1). SIMPER analysis indicated *Porites astreoides* to be the main species responsible for between-site dissimilarity (Table 3). Diversity measures for coral and gorgonian diversity showed high diversity at Baboon Cay in both indices, however that for the Shannon

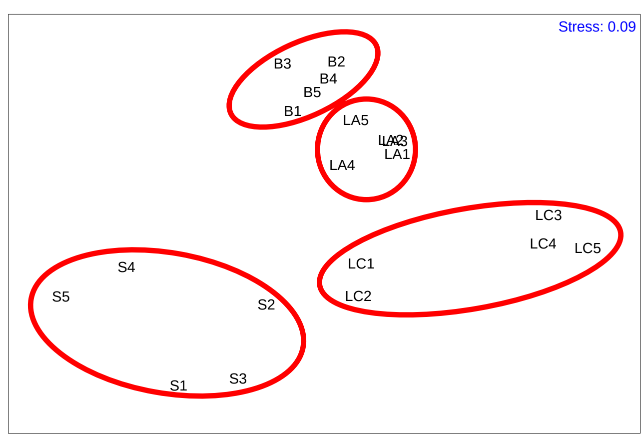

Figure 6. Multidimensional scaling ordination showing changes in Coral and gorgonian frequency abundance for the 4 sites. MDS based on Bray Curtis similarities from √-transformed data. B = Baboon Cay, LA = Little Askil Cay, S = Seal Cay & LC = Little Corn.

(H') index was highest at Seal Cay and that for the Brillouin Index (HB) highest at Baboon Cay. Both showed a decrease at Little Askil Cay, with the lowest occurring at Little Corn Island.

Location	% disimilarity	*Sp.* contributing to 60% between site dissimilarity
Baboon vs. L. Askil	53.17	*P. astreoides, A. tenuifolia, A. agaracites*
Baboon vs. Seal Cay	79.18	*A. tenuifolia, A. agaracites, P. astreoides*
Baboon vs. L. Corn	66.37	*P. astreoides, A. tenuifolia, M. complana*
L. Askil vs. Seal Cay	80.59	*P. astreoides, D. clivosa, D. strugosa*
L. Askil vs. L. Corn	54.39	*P. astreoides, M. complana, D. clivosa*
Seal vs. L.Corn	79.73	*P. astreoides, M. complana, M. annularis*

Table 4. SIMPER analysis for coral and gorgonian species abundance showing the percentage dissimilarity and which three main species contributed to approximately 60% of between site dissimilarity.

3.3. INDICATORS

Pearson's correlations between sedimentation rate of different sedimentation constituents and the species abundance data revealed several positive correlations with sedimentation-tolerant coral species. Abundance of *Solenastrea bournoni* showed a strong positive correlation with the acid insoluble (inorganic) non-calcareous component (R = 0.999, p = 0.001), as did *Agaricia tenuifolia* (R = 0.957, p = 0.043) and *Agaricia agaracites* (R = 0.989, p = 0.011). *A. agaracites* also showed a significant correlation with combined inorganic and organic content (R = 0.976, p = 0.024), as did *Siderastrea radians* (R = 0.953, p = 0.047). *A. tenuifolia* showed further correlation with combined inorganic & calcareous content (R = 0.950, p = 0.05).

Positive correlations of sedimentation intolerant species were found between *Porites porites* and turbidity (Secchi disc) measurements (R = 0.964, p = 0.036), with further correlations between Secchi disc readings found with the abundance of crustose coralline algae (R = 0.952, p = 0.048).

A *Porites astreoides* colour morph index showed a decline in the ratio of brown to green colony morphs along a gradient of decreasing terrestrial influence (one-way ANOVA, F = 17.47, p <0.001, Fig. 7), however, correlation with the acid insoluble non-calcareous sedimentation component revealed no significant relationship (R = 0.828, p = 0.172).

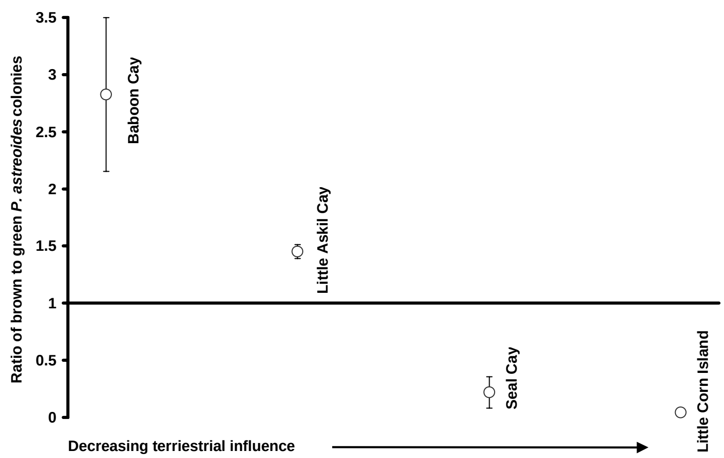

Figure 7. *Porites astreoides* colour morph index with standard deviation. Showing a decrease in ratio's along a gradient of decreasing terrestrial influence. With a value of 1 indicating total similarity, above 1 indicating greater abundance of brown morphs and below 1 a higher profusion of green colony morphs.

4. DISCUSSION

Previous experimental studies aimed at trying to assess the effects of sedimentation on corals have, to a large extent, been biased towards inorganics, with most experimental studies of sedimentation effects employing calcareous sediments or sediment with organics removed [190, 201-203]. Such studies do not give a reliable indication of coral response to runoff related sedimentation, as studies have demonstrated increased growth rates as a result of calcareous sedimentation [192] and increases in total sedimentation [204, 205]. Similarly, studies indicating the presence of healthy reefs in areas of high sedimentation [195-199] show that total sedimentation rates are not a good proxy for measuring coral responses. Many temperate examples [211-214] show that sediment and seston quality have an important effect on benthic organisms. It is only recently however, that studies have started examining the effects of sedimentation quality on tropical coral reef habitats (e.g. Fabricius & Wolanski 2000).

Such studies are beginning to show important effects of the organic content of sediment on feeding success and the clogging of filter feeding apparatus [215, 216].

Location	Sedimentation rates ($mg.cm^2.d^{-1}$)	Study
Discovery Bay, Jamaica	1.1	Dodge et al., 1974
St Thomas, USVI	1.6	Rogers, 1982
Puerto Rico	2.6	Rogers, 1983
Phuket, South Thailand	53.3	Scoffin et al., 1997
Cahuita, Costa Rica	30-360	Cortes and Risk, 1984

Table 4. Sedimentation rates for traps 50cm above bottom substrate for previous studies.

This study looks at the different fractions (organic, acid-insoluble non-calcareous, calcareous) of sedimentation and examines how these change with distance from a terrestrial runoff source. Although the total sedimentation rates at the inshore site were considered high (3.7 $mg.cm^{-2}.d^{-1}$) compared to oceanic situations in the Caribbean, they appear relatively low when compared to those of Thailand and more importantly other Central American levels such as those in Costa Rica (Table 4).

The inshore site (Baboon Cay) was influenced mainly by terrestrial runoff and had the highest total sedimentation rates. This was demonstrated by a high rate of acid insoluble non-calcareous sedimentation. Although dissolved organics were not measured due to time constraints, the low Secchi disc readings indicated high turbidity, also possibly as a result of increased dissolved organics at the inshore site. The biological effects of such an influence may include reduced photosynthesis [217], increased pollutants through mineral dissolution and increased prevalence of disease [218, 219]. The high levels of calcium carbonate at the inshore site compared to those offshore may be a function of increased productivity, which is often associated with nutrient enrichment as a result of runoff [220]. This was supported by observations of calcareous diatom frustules in the Baboon Cay sediment samples. Another explanation is that the high calcareous content was of riverine origin, however, examples from Belize found rivers generally contained low particulate carbonates even though there was limestone in the catchments [221], and this suggests higher productivity as the more obvious explanation. The difference in acid insoluble non-calcareous sedimentation and total sedimentation rate at Little Askil Cay suggest the terrestrial influence does not extend that far offshore. The increase in calcareous fraction between Little Askil Cay and Little Corn Island combined with the increase in organics (which was attributed to increased algal detritus as a result of wave energy increase) suggests that resuspension by wave energy plays an increasing role offshore. This was supported by the decreasing turbidity at the offshore sites. Had the increase in organics been due to increased dissolved or fine particulate organics an increase in turbidity would have been expected. Although the extent of resuspension was not assessed in this study, field observations indicated an increase due to higher wave action. Scoffin et al [222] observed similar results in Phuket, South Thailand, where inshore waters had high turbidity as a result of terrigenous solids and showed a decrease offshore as exposure to wave energy increased resulting in an increase in locally produced carbonate sands.

The effects of fine organic particulates although previously largely ignored in sediment studies on coral reefs [190, 223, 224] is thought to play an increasingly crucial role in coral reef health especially its ability to smother organisms and to clog filter feeding apparatus [215, 216]. The increased wave energy and floating algal detritus offshore however, masked the expected decrease in organics often associated with runoff in the present study. Although the widespread belief is that sedimentation decreases diversity and total coral cover [225-227], this study showed the site with the highest sedimentation rates to have the highest hard coral diversity and live coral cover. Many studies have shown similar results, indicating that diversity and live coral cover may be poor indicators of sedimentation impacts, and no inference should be attempted about the general assumption of a connection between high diversity and high environmental quality [228]. Because of this, other possible indicators were examined. Several positive correlations were established between levels of terrigenous acid-insoluble non-calcareous sedimentation and known sedimentation-tolerant coral species. The strongest of these was with abundance of *Solenastrea bournoni*. Two species of Agaricia (*A. tenuifolia* and *A. agaracites*) showed similar correlations. Although reported correlations cannot prove causality because of large number of factors influencing coral distribution, they may give an indication of some of the structuring influences involved. Much of the dissimilarity between sites was due to the abundance of *Porites astreoides*. A study conducted by Gleason (1998) found distributions of green and brown *P. astreoides* varied predictably with differences in sedimentation rates: higher levels of sedimentation corresponded with a lower proportion of green colonies. Although these differences in sedimentation tolerance could be due to pigment changes which are known to affect photosynthesis rates [229], Gleason (1998) found brown colonies were more efficient at shedding inorganic particles. Although no correlations were established between the different sedimentation fractions, a colour morph index for this study revealed a decreasing trend in the ratio of brown to green colony numbers along a gradient of decreasing terrestrial influence. Although *P. astreoids* and *A. agaricites* are considered sensitive to sedimentation [228], their higher abundance on polluted reefs may result from the secretion of bacterial resistant mucus envelopes that are not secreted by other coral species [230]. Many of the dominant species found at polluted sites also reproduce by brooding larvae and this may be an additional factor contributing to their relative dominance.

In areas of sedimentation, coral growth rates and carbonate accretion are thought to decline [231], in such cases *Agaricia tenuifola* may act to increase sediment trapping due to its baffle-like growth form providing favourable environmental conditions for reef growth [232].

Although this study attempts to describe the spatial distribution of sedimentation quality in the Pearl Cays it must be noted that the characterisation of the sedimentation regime at the sites described is based on data collected over a 24hr period. It is likely that sedimentation rates will change on a daily, weekly and seasonal basis in response to inputs and local wave energy. It must therefore be acknowledged that the temporal variability in sedimentation rates and affects on quantity, quality and persistence will be hugely important. Further limitations encountered are those of sample size relating to video collection. Although 5x50m transects per site is standard practice [233], it could be argued that when comparing reef areas of different sizes (e.g. Baboon Cay and Little Corn Island) the sampling at the smaller reef complex would be more representative than at the larger reef site as a result of earlier species saturation.

This study indicates that higher sedimentation rate does not always correlate with reduced coral diversity and live coral cover. The presence of known sedimentation-tolerant species appeared to be closely correlated to terrigenous derived constituents rather than to total sediment volume or the calcium carbonate components. Although any conclusive results at the offshore sites were masked by wave energy increase, it is likely that the inshore site was structured by terrestrial influence. It is concluded that a more complete approach to sedimentation studies is required which should be based on sedimentation quality as well as quantity.

5. ACKNOWLEDGEMENTS

Special thanks to Reefmap team for their help and support with the project, without which this work would have not been possible. I would especially like to express my gratitude to the Atlantic Biological Corridor project (CBA) for the use of their boat and Pangero, Joe Ryan for his help and knowledge of the local area, Dr Rob Nunny for his support, advice and constructive criticism. Finally my thanks go to my supervisor Dr John Bythell and the outstanding survey team for their tireless efforts with data collection: Phil Broadhurst, Clare Drakeford, Marcos Clowes and Pallin. This research was supported by The Royal Geographical Society with the Institute of British Geographers, The University of Newcastle Exploration Society, The Rufford Foundation, PADI Project Aware, Coral Cay Conservation, The Gilchrist Educational Trust, Brooksbank Valves Ltd, P&O, RAAS-Asdi-RAAN, Dive Little Corn and Casa Iguana.

DISCUSSION

1. THREATS TO THE CORN ISLANDS' LOBSTER FISHERY

Recent years has seen a major decline in catches and CPUE in the artisanal fisheries as well as the industrial fisheries [1] [Daw, this study]. Some of the potential reasons for this decline have emerged in the reefmap project through interviews with experts, authorities and the fishers themselves. The main concern shared by all parties surveyed during the fisheries study was that the lobster fishery is being overexploited; however, perceptions of who the main culprits are remain significantly divided [Gunnartz, this study] and this has resulted in a non-progressive and accusatory management situation on the Islands. In contrast, indirect reasons for the decline of the lobster fishery such as destruction of inshore lobster nursery habitat due to sedimentation, coastal pollution and sea-level rise were rarely identified as having any significant impact on lobster populations yet these impacts could represent a serious threat [99, 133, 144]. The main concerns and threats to the lobster fishery that have been identified in the reefmap study are detailed below along with suggestions for further research and management:

1.1. REGIONAL ENVIRONMENTAL CHANGE & LOBSTER LIFE CYCLES

The perspective of most of the fishers involved is confined, focussing on threats in their local area. However, because of the migratory character of the lobster lifecycle, other regional large scale changes, and even local changes in faraway lobster habitats, may have consequences on the Nicaraguan lobster stock [133]. Land use change and increased deforestation could for example lead to increased sedimentation on the coast with adverse impacts on lobster habitats [Velterop, this study] and directly on the lobster recruits [99]. Changes in oceanic currents as a result of climate change may well lead to changes in the dispersal and settlement patterns of lobster larvae and result in decreased recruitment of juvenile lobsters to the fishery [99, 133]. Fishing effort and habitat changes in other regions where juveniles migrate from could be influential in the decline of the Nicaraguan spiny lobster. The mainland inshore coastal areas (mangroves, seagrass and algal habitats) are likely to be an important habitat for postlarval and juvenile lobster recruits [133], this is also a shrimp trawling area [1] and there is a possibility that shrimp trawling may damage lobster habitat and threaten recruitment to the fishery.

- **There is a serious need for further investigation of the ecology of the Nicaraguan Spiny Lobster populations, to identify areas that support high recruitment and to minimise threats to these areas.**
- **Ecological studies should be undertaken in collaboration with the coast's lobster fishers (especially the divers) who are aware of the habitats and likely have a wealth of local knowledge on important juvenile habitats.**
- **Interviews with the fishers revealed two kinds of lobster; red and white [Daw, this study]. To improve knowledge of the lobster population dynamics it would be important to do further investigation into these two groups and determine what separates them (e.g. genetic differences, different habitat/life history, different phases in life).**
- **Climate change impacts such as changing offshore currents which influence larval dispersion, sea level rise, increasing rainfall and sedimentation which may cause a decline in nursery habitats should be investigated further on a regional scale.**
- **Efforts should be put into a regional scale research project into the lifecycle of the lobster and the relation between populations in the Caribbean basin.**

1.2. REGULATION OF THE COAST'S INDUSTRIAL FISHERY

The industrial fisheries are the main concern of the artisanal fishers. The main reason for their concern is fierce competition, as the high fishing capacity of the industrial fisheries has grown. Even though the official limit of number of traps is 1600 the actual amount is often double or quadruple (The official limit of 1600 traps per industrial boat is clearly not being followed [26], when most industrial boats have 3000 to 6000 traps (according to interviews with industrial captains) [Gunnartz this Study]. Underestimation of trap numbers in official estimations may be the cause of errors concerning the decline in Catch per Unit Effort (CPUE), which may in fact be greater than calculated. Controlling the amount of traps on each industrial vessel is difficult. The industrial fishers use GPS to mark their traps and pick them up using hooks. It is more or less impossible to make sure all the traps are counted at a single control, as there may be excessive numbers of traps submerged in unknown positions. Another reason for discontent of the artisanal fishers is that they see industrial fishers as foreigners exploiting their resources. In one sense this may be accurate as many of the leading positions on the industrial boats are held by Hondurans [23]. There is also concern of illegal fishing fleets from neighbouring countries violating national boundaries and impinging on Nicaraguan fishing areas [23, 24]. The competition for space has grown fierce as artisanal fishers move further out due to dwindling catches in near-shore areas [Daw, this study], and the 25 nm area reserved for artisanal fishers is often violated by industrial fishers [Gunnartz, this study].

- ► **A few of the fishers mentioned that the industrial fishers previously used to have a stationary fisheries inspector onboard at all times; this could be a possible way of ensuring enforcement of regulation (this strategy would require a system that minimised pressure of corruption on the inspector, which is likely to be high).**
- ► **Fishing effort could be monitored by installation of satellite vessel monitoring systems (VMS) on all industrial boats. This would allow the department of fisheries to monitor the location and fishing effort of the fishing fleet and may also help with the identification of illegal vessels.**

Furthermore if this was done in collaboration with the fishers as part of a research rather than an enforcement programme, data on catches and habitats could be incorporated to construct a clearer picture of the life cycle ecology of the spiny lobster on the Atlantic coast, thereby guiding ecosystem based management and promoting co-management. Cost, disputed territorial boundaries of Nicaraguan waters and the political acceptance of VMS by fishers are a few of the potential problems with VMS but these limitations are not insurmountable. The cost of such systems is rapidly declining and aid funders might be interested in supporting a fisheries monitoring / management project, especially if regional cooperation could be attained between the governments of lobster fishing countries and the lobster fishers as part of a co-management / research strategy.

1.3. NON-ADHERENCE TO FISHERIES REGULATIONS

Even though a great part of the artisanal fisher community in Corn Islands is positive to all current regulations on lobster fisheries, the reality is that everybody agrees that a great majority do not follow them strictly. The reasons for not complying with the regulations vary but the most common reason is income-loss and lack of confidence in the enforcement of the regulations, i.e. "what does it matter if I follow the regulations if nobody else does". In some cases lack of education and information could be a reason, e.g. some fishers claimed to keep spawning lobsters that they catch, because they believe the spawn to be destroyed as soon as the lobster is removed from the water. A low risk in dealing with small and spawning lobster provides further incentive to fishers to continue this trade. In the case of the artisanal fishers, there is a practically non-existent control at the landing sites (at acopios), and the industrial fishers can circumvent the controls by shipping illegal catch to shore with small boats before they enter port. Some fishers have also indicated that small lobster has been included in 'cacho', the meat from the head of the lobsters that the industrial fishers sell. Spawning lobsters are cleaned of their spawn before they are taken ashore.

- ► **The fishing effort of the industrial fleet could be decreased by reducing the number of industrial vessels. A step in this direction was taken in 2003, when the number of licences for operating industrial boats was reduced for the first time since the opening up of the fisheries in the 1990s.**
- ► **Ensuring better enforcement of the inshore artisanal fishing area would enhance the livelihood security of the small-scale artisanal fishers, and may promote their trust in the regulatory authorities. Installation of VMS (see above) might solve this problem. Alternatively, a system for fishers to report observation of violations could be set up, where the reporting fishers could remain anonymous.**

- **Frequent and random controls of catches at the artisanal landing sites (acopios) could make it more difficult for the fishers to trade in small and spawning lobster. According to some fishers there are ways of telling if a lobster is spawning by the shape of its tail, this should be applied in controls to distinguish "cleaned" spawning lobsters.**
- **In order to minimise the market for small and spawning lobster, authorities should form a partnership with restaurants and hotels on the islands and other parts of the country. This could form an important base for reporting attempts to sell illegal catch, to an information campaign aimed at customers, and controls at restaurants. A special marking system could be introduced for cooperating restaurants. This would be combined with a campaign informing tourists (a main group of customers) about the marking scheme, thereby giving an incentive to restaurant owners to join the scheme.**
- **Many fishers leave their traps in the water during closed seasons making them ineffective. The main reason for this (according to the fishers) is that the fishers cannot afford the petrol to fetch all traps and that there is lacking space to put up traps. A centralised scheme for getting traps out of the water for the closed season should be organised, possibly renting an industrial boat for the job to fetch all artisanal traps.**
- **Fishers also leave traps in the water due to lack of confidence in the compliance of other fishers. It is therefore imperative to keep track of exactly how many traps each fisher has and to make sure that they have been removed. In order to give further incentive to artisanal fishers to follow this regulation, industrial fishers must be better regulated, keeping track of their trap numbers and making sure they are all removed during the closed season.**
- **A forum for dialogue and cooperation between fishers, fisheries companies and authorities should be set up to discuss more effective implementation and enforcement of regulations (see section *Fisheries management organisation* below). This could help deal with practical issues (such as how to recognise the size of lobster under water, which is a potential problem for divers), education (e.g. clearing up misunderstandings concerning spawning lobster and conveying information on lobster ecology and management) and to improve confidence between fishers and authorities.**

1.4. HABITAT DAMAGE

Many of the diving fishers expressed concern that traps may be affecting the bottom substrate through abrasion or from blocking out sunlight. This is especially a concern related to the closed season, when many fishers leave their traps to rot or disintegrate in the water. Wiring left over from the traps could pose a potential problem for marine animals. Some are also worried that a wood treatment that has been introduced recently may leach into the marine environment. Diving could also potentially be a problem as divers could destroy substrate in order to get hold of the lobsters. Pollution from boats has also been mentioned as a concern.

- **Research should be conducted in collaboration with the fishers on the effect of traps on substrate, using observational as well as experimental approaches. It should include different types of traps, made of different materials. This type of specific small-scale study would be appropriate for a master's thesis.**
- **The potential effects of diving on habitat should be further investigated, leading to a code of conduct for divers. In order to ensure the effectiveness of this type of scheme, it needs to be undertaken with the participation of the divers themselves and in combination with an education programme about the effects of habitat destruction on the lobster stocks.**
- **A system should be set up to keep account of the exact number of traps that each fisher possesses. At each closed season all traps should be taken out of the water, dysfunctional traps should not be dumped in the sea, but recycled (e.g. as fire wood or compost).**

1.5. ARTISIANAL OPEN ACCESS SYSTEM

An open access system of the artisanal fisheries has lead to an uncontrolled increase in fishers and also complicated the enforcement of regulations. The existing licensing system could serve as a base for controlling the artisanal fishing effort and limiting access. In limiting access it is important to look at impacts of interventions on the livelihood security of the fisher community as a whole, taking special consideration of vulnerable groups lacking alternative options.

- ► **An in-depth participative socio-economic study involving all groups of fishers and other fisheries stakeholders should be undertaken before any limitation of licences is implemented. The study should examine the impact of proposed licensing schemes on the livelihood security of groups depending on the resource. Special efforts should be taken to minimise effects on more vulnerable groups with little or no alternative options for income. The study should include a proposition for alternative income generation for groups affected by the licensing system.**

1.6. DIVING?

Diving is seen by many trap fishers in Corn Island as an important reason for the decline of the fisheries. This is mainly because they believe that it is more efficient than trapping and that divers destroy habitat more than trapping. However none of these assumptions have been scientifically proved (as far as the author knows). Another reason for general discontent with diving from the part of the trappers is that they suspect divers of trashing traps and stealing catches. There is also a great concern for the health problems associated to lobster diving, which have lead the government and international groups to plea for a ban on diving.

- ► **A study should be undertaken to determine the actual effects of diving on lobster populations and habitat, in comparison to trap fishing. This should preferably be done in collaboration with fishers, taking advantage of their experiences as well as ensuring a greater integration of the study results into the fishing community. The results of the study should then be linked to potential management interventions, outlined in collaboration with the fishing community. Fisher participation, from the start, in such a research project would promote greater understanding and support within the fisher community for a subsequent management intervention.**
- ► **A potential ban on diving would require a large-scale study into the effects of such an intervention on the livelihoods of the divers and their families as well as indirect effects on economies depending on the lobster diving industry. Such a study should be participative, involving the divers and their organisations in a discussion to find alternative solutions for income generation. Collaborative efforts should be made to seek financial support from international bodies to ensure a smooth transformation of fishers from one technique to another, ensuring a sustained livelihood security for divers (as an example the diver organisation on Corn Islands, APAM, has already prepared an application for such a programme).**
- ► **The specifics of the implementation of a potential ban should be planned out in collaboration between authorities, fisheries enterprises and the fishers and their organisations. The divers are one of the most organised groups of fishers, and this may facilitate a government dialogue with the group as a whole.**
- ► **To ensure better support from the diving community in response to a potential ban, it should be implemented on a longer time-scale with a gradual phase-out. This will allow the diver community to adapt to the new conditions and switch to other fishing techniques such as trapping, or to other alternative income generation. A possible way of doing this (as proposed by a Corn Island fisher) would be to allow diving only on certain time periods (some days of the week or certain weeks). The time periods assigned for diving could then be gradually decreased over 2 to 3 years. This type of directive could be regulated by the amount of filled air bottles being sold to divers.**

1.7. TECHNICAL IMPROVEMENTS

Recent technical improvements, such as the introduction of GPS and improvements in trap structure, may lead to increased fishing pressure even though the apparent measures of effort (fishing days, number of boats etc.) remain unchanged. Miscalculation of the advances of fisheries technology have previously been the cause of collapses of stocks [234]. It is therefore important to integrate this technical progress in fisheries models and to adapt management interventions accordingly.

- **Comparative studies should be undertaken in collaboration with fishers, examining the efficiency of different fishing techniques (e.g. trap design, diving vs. trapping, baiting etc.). The results of this study should be integrated in fisheries models.**
- **Guidelines should be set for trap design. In order to secure effective enforcement of guidelines as well as trap functionality, they should be set up in dialogue with the fishers. Together with authorities and expertise the fishers may find alternatives to practices such as using smaller lobsters to attract catch; a technique which prevents many from following regulations on having openings in traps to let out undersized lobster.**
- **A study should be carried out to determine the impact of improved navigational techniques on the pressure on and range of fishing areas, and thereby possible elimination of important refuges for recruitment stock. The results of this study should be integrated in fisheries models.**
- **Corn Islands and the RAAS has a relatively small diver community compared to the RAAN, and might be a suitable place for a pilot study on a ban on diving. Also, part of the diving community here is relatively positive towards a potential ban as long as they can be assured that they will have access to alternative techniques (i.e. traps).**

2. THE INCREASE OF FIN-FISH FISHERIES

The decline of the lobster fisheries, and the introduction of increased periods of lobster fisheries closure, has lead to increased fishing pressure on fin fish. The price for fish is very low compared to lobster, as there is currently no infrastructure for delivering fresh fish to markets on the mainland, and frozen fish are not of great market value. Nevertheless, few artisanal fishermen have alternative livelihoods during the closed season (introduced in 2002), and many have therefore started to rely more heavily on fishing with hook and line. This sudden increase in fishing pressure on fin fish could have not only direct consequences on fished species' populations, but also indirect large-scale ecosystem effects such as a phase shift to macro-algal dominance on the coral reefs (see section 4.1 later). Many fishers bear witness of a decline in big predatory species close to the islands and bait fish has also becoming scarcer and there have been complaints of fishers coming over from Great Corn to Little Corn to catch bait fish. It is therefore important to closely monitor catches of fin fish and bait fish and look into how changes in these populations might be affecting the ecosystem as a whole.

- **A research project should be undertaken to asses the large-scale of effects of fin-fish fisheries on coastal ecosystems.**
- **A system should be set up for close monitoring of catches and changing fishing pressure on fin fish. Collected data should be used to model the state of the stocks to keep fishing effort at a sustainable level. By-catches should also be included in the monitoring system. Students from the programme in fisheries management at URACCAN undertook a brief training survey and assessment of the fin fisheries during the reefmap project, which could serve as a precedent to a long-term collaboration between fisheries authorities and the university to monitor the fin-fish fisheries.**
- **The habitats of fished species should be identified (especially spawning and nursery grounds) and the need for protection of these habitats should be assessed in order to ensure recruitment and stock sustainability.**

3. GENERAL CONSIDERATIONS FOR FISHERIES MANAGEMENT

3.1. CO-MANAGEMENT POTENTIAL / FISHER ORGANISATION

Fishers' participation in management in the Corn Islands is likely to contribute to better adherence to regulations and improve the effectiveness of management interventions. However, while there are intentions from the part of authorities to promote fisher participation management, the current lack of organisation of the fisher community [17], Gunnartz, this study] presents a serious barrier. Fisher involvement in management and co-management measures commonly require a structure for just representation of all fishers; if some fishers feel alienated from the project they may choose not to participate, and this could break up the whole initiative [235]. For co-management to develop in Corn Islands it is imperative to form fisher organisations which include the whole fishing community, where all fishers can make their voice heard, and management interventions and planning can be discussed.

Many of the fishers interviewed during the reefmap project expressed a keen interest in being part of an organisation. However due to a climate of general distrust within the fishing community and previous experiences of corrupt leadership, many fishers remain sceptical to new initiatives to form organisations. It is therefore extremely important to make sure that this process should be a well formalised, transparent process with emphasis on democratic principles. The structure of the organisation should be arranged by the fishers themselves. A network of smaller groups or organisations is likely to give fishers a wider range of choice as to how they want to participate. For example, some fishers may choose to be part of a more extensive collaboration including credit systems etc., while others may only want to participate in a forum for discussion.

Successful management initiatives on Little Corn Island may provide a role-model for organisation on Great Corn Island. The advantage of Little Corn's fisher community is that their cultural background and fishing methods are similar; this along with the small size of the community has contributed to the development of a fisher group with significant social cohesion. In contrast, Great Corn Island's fishers come from different cultural groups and use differing methods. In combination with a larger and more spatially segmented community, these factors have tended to fragment the fisher community. Establishing social cohesion amongst the fishers on Great Corn Island should be a key focus of any management program aiming to promote fisheries co-management and this will require a significant effort from community leaders.

The fisheries study has helped to identify key groups that could be approached in a further process of participation in management [Gunnartz, this study]. It has also demonstrated a variety of information that fishers could contribute to fisheries management and planning [Daw, this study]. This has laid the groundwork for an ongoing process of participatory research which could contribute to the monitoring and management of the resource and particularly the artisanal fishery. However for this process to lead to fisheries co-management there needs to be a framework in place for this information to be fed to the national level and lead to legislative provisions. If fishers feel that they are contributing to effective legislation and management, are participating in the decision making and are having their voices heard and understood they are much more likely to abide by the legislation. Furthermore if they are more organised they are also much more accessible to educational programs (for example regarding pollution threats and lobster ecology) and could also contribute to the development of such programs.

- ► **A task-force should be set up to facilitate the organisation of the fishers and work towards fisher participation in management. This task-force should preferably be composed of persons that the fisher community as a whole hold in high esteem and trust. Non-partial outsiders can also play an important part in conflict management. Facilitators should function as a conducer for the fishers' views and ideas for how to get organised and make their voices heard on higher levels. The task-force would benefit from the support of expertise on collective action, and participatory techniques and methodology.**

- ► **A participatory research process should be initiated on the islands to support the task-force with information to assist conflict management (as described below).**

► **The municipal fisheries officer, assisted by the municipal fisheries commission, could play a more active role in fisheries management by being actively involved in the above mentioned processes.**

A potential co-management process will need to put special emphasis on conflict management in order to create an environment for consensual and democratic decision-making. The Fisheries Social Study [Gunnartz, this study] has identified groupings of fishers based upon differences in cultural, social and functional characteristics, as well as perceptions of management measures. These groups could be used as a starting point for organising a participatory research programme focussing on differences in belief systems within the fisher community. Building the results from the Fisheries Social Study, this type of project would support facilitators in conflict management and enhance understanding within the fisher community to reasoning behind differing perceptions. This would promote dialogue and enable prediction and a planned approach to potential conflicts that could otherwise pose a threat to efficient user participation in the management process. An outline proposal for such a project is currently being developed by the reefmap team (see mind**map** proposal later).

4. ECOSYSTEM THREATS, RESEARCH NEEDS AND MANAGEMENT IMPLICATIONS

4.1. THREAT OF AN ECOLOGICAL SHIFT ON THE ISLANDS' INSHORE REEFS

A synergistic combination of overfishing of herbivorous reef fish and nutrient enrichment (often resulting from pollution) is one of the most common causes of algal phase shift in Caribbean coral reefs. Phase shifts occur when the conditions are right for algal dominance and disturbance events (such as a storm or hurricane) reduce the biotic cover of the reef leaving the substrate open to competition and subsequent domination by fast growing macro algae that out-competes the hard scleractinian corals [102]. The consequences of a phase shift on the Corn Islands' coral reefs would be a halt in reef formation and a gradual breakdown of the reef structure. This could have serious consequences, including loss of coastal protection against storms and hurricanes, destruction of the lobster fisheries nursery habitat, saline intrusion of the islands aquifer, and a decline in coastal agricultural productivity due to saline contamination of coastal soils.

On the Corn Islands a majority of the fishers are employed in the offshore spiny lobster fishery. This fishery has seen a significant decline in catches in recent years, even with an increase in fishing effort due to a migration of fishers to the islands [1]. At present, the lobster fishery in Nicaragua is regulated by a closed season and during this period the lobster fishers turn to other income generating activities. As well as service industry jobs associated with tourism such as taxi drivers and construction workers, fishers may turn to the far less profitable exploitation of inshore reef fish. At present this exploitation is likely to focus primarily on predatory fish such as snappers and groupers which are the most valuable fin fish commodity (although the use of fish traps by some fishers is less selective and may also impact herbivorous fish populations). Depending on the pressure on the fin fisheries, this could change.

In 2004 the closed season for lobster fisheries was extended from two months to four months to restrict fishing effort and to combat the decline of lobster catches [1]. A continuation of restriction of effort and decline in catches in the lobster fisheries, could possibly lead to an increase in the exploitation of inshore reef fish populations (see Fin Fish Fisheries below). Effort may then be transferred inshore and increasingly onto the exploitation of herbivorous reef fish; a trend which has been observed in other areas of the Caribbean [236].

► **It is therefore evident that checks need to be put in place to monitor and manage levels of inshore exploitation of fish, and to monitor and control coastal pollution.**

► **It would also be advisable to identify and outlaw destructive and unselective fishing methods, and to ascertain the timing and location of fish spawning events so that these events can be protected from exploitation.**

Ryan and Broegaard [63, 86] hypothesise that Corn Island's freshwater aquifer is geologically connected to the near-shore reefs and that sewage from the island may be leading to inshore nutrient enrichment. The coral reef survey in this study suggests that algal overgrowth is already a problem on some inshore reefs around Corn Islands. Furthermore, the wetland pollution study shows that there is concern amongst the Islands' community regarding the problem of coastal pollution. If these assumptions and perceptions are correct, if coastal pollution is left unchecked, and if inshore fishing reaches unsustainable levels, this scenario has all the prerequisites of an ecological shift to macroalgal dominance on inshore reefs. The consequences of these synergistic effects would only become widely evident when the next storm disturbance strikes the islands.

This report has demonstrated (through the wetland pollution study and the fisheries studies) that monitoring of pollution and of fisheries exploitation can be achieved through low cost approaches in collaboration with the local community. This approach could certainly be extended to participatory management and direct action such as coastal cleanups and education campaigns in collaboration with the islands local government, NGO's and the coasts universities. Such an approach is also highly advisable as it helps to ensure that resource users are aware of the issues and are involved in developing and implementing solutions. During the last year, the reefmap team have been elaborating a proposal for a community-based participatory environmental monitoring programme (see Future Research).

4.2. WETLANDS AND THE THREAT OF CLIMATE CHANGE

At present the Corn Islands do not have centralised waste water treatment and the islands' coastal wetlands therefore act as a natural waste treatment plant by assimilating nutrient rich human waste which enters these wetlands through the ground water supply. Although wetlands can assimilate large quantities of nutrients, the capability of the islands' wetlands to deal with high levels of nutrients is limited [160]. Although the reefmap wetland pollution study did not show a clear indication of ecological stress as a result of pollution, the study needs further replication and long term monitoring of pollution levels. Such a programme may reveal that these ecosystems are already stressed by rising pollution levels as a result of the islands population.

In any case, there is still a significant threat that any decline in the ecological stability of these freshwater ecosystems would lead to increased pollution input into the marine environment, and significant nutrient enrichment as well as contamination of the islands aquifer. Climate change predictions for the Caribbean over the next century indicate a significant rise in sea level and an increasing frequency of hurricanes in the region [113, 115]. On the Corn Islands, sea level rise, coastal erosion and extreme storm events all have the potential to cause lowland flooding and seawater inundation of the islands' coastal wetlands. A study of the Corn Island geological makeup for example showed that more than one third of the island is below half a metre above sea level [164]. With predicted sea level rise easily within that range before the end of the century this demonstrates a significant threat to the islands' wetlands. Representatives of the local communities have expressed their concern for the reduction of certain beaches due to sand extraction for construction purposes. This practice is yet another threat to the coastal defences that protect the wetlands from saline intrusion.

Any prolonged increase in salinity in these freshwater ecosystems would affect their ecological stability. If they are already heavily stressed by high pollution levels, this would most likely lead to nutrient enrichment of coastal waters, threatening important inshore marine ecosystems and impacting the islands fisheries resources and coastal defences. Furthermore, wetland decline due to saltwater intrusion may also lead to saline intrusion into the islands' freshwater aquifer, affecting coastal agricultural productivity and the islands freshwater supply.

Sea level rise and increasing storm activity in the Caribbean may be an inevitable consequence of global warming. However, on the Corn Islands these impacts will be exacerbated by human pressures such as increasing pollution, loss of coastal wetland protection (due to coastal development) and overfishing. There is an urgent need to increase the islands ecological resilience to climate change by conserving and managing human threats to critical coastal ecosystems. Strategic conservation and development planning with specific emphasis on waste management would help to maintain the islands' ecological stability and biodiversity, thereby contributing to the sustainability of coastal defences and the inshore fishery.

- **Reduce coastal pollution input through waste management planning and through guidance on appropriate technologies (affordable and small scale waste treatment for pit latrines) or consider centralised waste treatment.**
- **Educate communities about the how to dispose of different wastes in a way that minimises the environmental impact.**
- **Encourage private waste reuse and recycling and management enterprises.**
- **Prevent development encroachment that threatens the ecological integrity of critical coastal ecosystems (wetlands / seagrass beds / coral reefs) by using tools such as sensitivity mapping, development planning and environmental impact assessment.**
- **Require that all new larger developments provide a comprehensive review of how they will deal with waste disposal and provide developers with guidance on waste management and soil conservation practices.**
- **Set-up a long term participatory waste and pollution monitoring system. This could be done in collaboration with the Movement for the Defence and Dignity of Corn Islands who already have members trained in water sampling and analysis.**
- **Enforce legislation banning sand extraction for beaches through an education campaign and through a participatory beach monitoring programme.**

5. MARINE PROTECTED AREAS, MARINE PARKS AND ECOLOGICAL CONNECTIVITY

Marine protected areas (MPAs) are currently being promoted internationally as a fisheries and marine habitat conservation measure [237]. In the Corn Islands local plan the islands' local government (Alcaldia) and department of the environment (MARENA) expressed interest in creating a 'marine park' around the Corn Islands as a tool to enhance coastal ecosystem management and biodiversity conservation [17]. This idea has also gained support from some groups within the islands local community [Gunnartz, this study]. Additionally in a recent meeting of the FAO regional fisheries commission (WECAFC) along with a raft of other measures, the fisheries department (ADPESCA) recommended that closed areas should be used in sites which have been previously identified as having high levels of lobster recruits and pre-recruits [238].

MPAs can be used as a conservation and fisheries management measure to create refuges preserving recruitment stock for fished species and helping to protect important, vulnerable and unique habitats and biodiversity [237]. If placed in areas accessible for diving and snorkelling they could also promote the tourism value of an area and generate income for management and monitoring (. In many cases however, the rationale behind MPAs is questionable, and so-called "paper-parks" (parks that exist only on paper but are not effectively implemented) are not uncommon. Hence, implementation of an MPA on the Corn Islands would only be successful if it is based on a clear rationale; has local as well as regional and national support; is well integrated and formalised into legislation; and has an achievable, realistic and sustainable plan formulated for enforcement, monitoring and management. The data and maps derived from the reefmap project could potentially contribute to this process, but further research and assessment is required.

In 2001 a failed attempt was made by the Alcaldia to implement a no-take zone within a 2-nm zone around the Corn Islands (in an attempt to protect lobster stocks). The restriction had a lack of support from the community as a whole (with significant protest from the lobster diver community). Furthermore, because fisheries regulation is under national jurisdiction, many fishers realised that the local attempt was an illegal imposition and ignored the ban. This demonstrates the need for significant local and national consultation and participation in the formation of any proposed MPA on the islands. Moreover, the rationale for the placement of an MPA needs to be clearly identified in any proposal. For example, if the MPA is to protect lobster stocks what evidence is there that the protected area is an important recruitment area? If it is to protect biodiversity or ecological integrity, will fishing restrictions be required and will these impact any specific sectors of society? Improper siting of an MPA could shift fishing pressure onto more sensitive habitats or threaten the livelihoods of poorer stakeholders [2] issues such as these need serious consideration when planning an MPA.

An ill-planned protected area with inshore fisheries restrictions and minimal local consultation has the potential to marginalise poorer stakeholders and provide inequitable benefits to the more affluent fishers. Inshore artisanal fishers likely rely heavily on the near shore fin-fish habitats for subsistence and would be impacted by an inshore no-take area. More affluent fishers in contrast can afford to travel further offshore to exploit the lobster resource and would benefit from protection of the inshore spawning lobsters which are thought to migrate to the islands reefs.

In line with this study's principle objective, habitat maps have been created for the Corn Islands with a particular focus on discriminating the reef habitats. The most likely application of these maps is the development of a marine park in the proximity of the Corn Islands as outlined in the Corn Islands' management plan prepared by the Ministry of the Environment (MARENA) and the Corn Islands' Municipal Government (1999). However, it is as yet unclear what format such a park might entail and there are a number of issues that need to be considered. One of the most significant threats to the Corn Islands marine habitats is likely to be from fishing pressure and although management of coastal resources is under the jurisdiction of MARENA and the local government, regulation of marine fisheries is under the jurisdiction of the fisheries department (ADPESCA). In addition, the majority of the population of the Corn Islands are employed in the fisheries industry and would likely be directly affected by any no-take fisheries regulations implemented.

The examples of potential threats to the coastal ecosystems of the Corn islands clearly show that they cannot be managed independently of each other. Caribbean coastal ecosystems are known to be highly dynamic and interdependent [239] and critics of marine reserves often point to their failure to address external threats transported to the area [240]. It is therefore critical for policy makers to have an understanding of ecological connectivity at a variety of scales in order to mitigate and predict the consequences of coastal management or development decisions which indirectly affect fragile or protected habitats. In practice, this could prove difficult as it requires decision makers to be able to separate anthropogenic impacts from often significant natural environmental variation. Natural variation can be significant in the marine environment, hence long-term and well replicated environmental monitoring data is required to provide robust information support for coastal resource management.

The coastal habitat maps produced in this study provide an excellent starting point for the planning of a suitably replicated and well designed long term ecosystem research and monitoring programme around the Corn Islands. Monitoring data could be used to model the ecological connectivity between the different coastal and marine ecosystems, to assess the health and condition of the islands' coastal environments, to advise the management of human activities, and to help decision makers proactively mitigate any potential threats.

Studies of ecological connectivity are particularly important in the design of marine protected areas especially with regard to promoting fisheries. Source areas such as spawning sites and recruitment habitats need protection, but sink areas can be left open [241, 242]. In this context habitat mapping can therefore be seen as an important first step, but ecosystem monitoring and long term and localised studies of ecological connectivity are still required to assess recruitment dynamics before policy decisions are made on the design of any proposed protected area for fisheries management.

- **Any proposed marine park entailing a regulation of fisher's activities would require an extensive programme of government and local community consultation.**
- **Furthermore, if a marine park was designated, clarification of the responsibilities and jurisdiction of each organisation would be essential to ensure that any policy and regulation is successful.**
- **A task-force should be set up to discuss the rationale and feasibility of establishing an MPA in the area. The task force should consist of representatives from relevant bodies within national, regional and local government (MARENA, AdPesca, RAAS Regional Council, Corn Islands Municipal Council) and other stakeholder groups (such as local and regional NGOs, civil society and community organisations, fisher organisations, artisanal fishers, industrial fishers, fisher enterprises, tourism enterprises etc).**

- ► **The planning of a potential MPA should involve a full-scale assessment programme looking into socio-economic, legal and ecological aspects of the implementation of the MPA. It should strive to involve all affected stakeholders in research, planning, decision-making, implementation, and monitoring and evaluation. The assessment should determine the effect of the MPA on stakeholders and propose mitigation measures if necessary. Special effort should be made to involve and secure the rights of politically and economically marginalised groups whose livelihoods could be impacted by the MPA** [2]. **Stakeholder involvement in these processes will promote local support, and an effective, sustainable implementation of the MPA.**
- ► **Funding to support the establishment of the MPA could initially be sought from international and national funding sources, but the long-term running and implementation of the MPA should preferably be a financially self-sustaining process. Collaboration with local businesses, the development of eco-tourism enterprises, and park entry fees could potentially contribute to this process.**

6. TOOLS AVIALABLE FOR ENVIRONMENTAL MANAGEMENT

A lack of financial resources and limited institutional capacity are characteristic of developing countries such as Nicaragua. They pose serious obstacles to the implementation of long-term and wide spread monitoring programmes to the extent that coastal resource monitoring has been sporadic, localised, and is often dependant on limited external financial support and expertise. The lack of a long-term and extensive marine resource monitoring in Nicaragua is undoubtedly a limitation to effective and well informed resource management, but this does not mean that management is un-informed. Significant advances in the understanding of ecological processes within tropical ecosystems in recent years, combined with large-scale monitoring programmes such as CARICOMP, AGRRA and MBRS, have provided and will continue to provide a generic understanding of ecological processes that can be applied to local level coastal resource management. By utilising this generic information, and a precautionary approach combined with local experiential knowledge, managers are presented with a wealth of information that can be used to guide decision making at the local level in Nicaragua.

The habitat assessments included in this study (Chapter 2, Section C) are based on a review of generic scientific knowledge combined with local perceptions. This combined approach has helped to indicate the principle uses and threats to the Corn Islands marine and coastal habitats, and provides the basis for a conceptual model of ecosystem structure and connectivity. For example, a multitude of studies from around the world have demonstrated the importance of coral reefs as important in coastal defence, coastal fisheries and biodiversity. Such generic knowledge, combined with local ecological knowledge and spatial information on the distribution of the resource, provides a basis for a series of management and policy recommendations for the islands.

The rationale for the policy recommendations made in the habitat assessment section is therefore primarily based on a series of ecological assumptions. There is a need for these assumptions to be validated from empirical observations obtained from monitoring studies for decision making to be reliable, and the recommendations generally represent a precautionary approach to management.

- ► **Resource monitoring should be undertaken by the local government with the participation of community stakeholders. This would provide the empirical evidence to validate assumptions made about the importance of local habitats.**
- ► **Further studies would help justify spatial policy decisions such as protected areas or zoning plans brought in by central government, and builds the capacity of local decision makers to understand ecological connectivity.**

7. INFORMATION MANAGEMENT FOR MONITORING AND MAPPING

In a developing country like Nicaragua resources may not be readily available to undertake monitoring, and local decision makers have limited access to training and information due to restricted finances and poor communications. Furthermore, those who do gain access to training and information are often attracted to better jobs in the commercial sector or with national institutions, leaching management expertise from the local level.

The Corn Islands Environmental Management Plan [88] is based on various sources of knowledge which are contributed from different levels of government, universities and local and international NGO's & consultancies. These include:

- Externally acquired 'expert' knowledge gained from training and interaction, communication with regional and international experts (contributed primarily by central government and international consultants).
- Locally acquired scientific knowledge from (mostly) short term and localised scientific monitoring and assessment projects (contributed primarily by universities and international consultants / NGOs).
- Locally acquired experiential knowledge gained from communication with resource users and local stakeholders (contributed primarily by local government & NGOs).

If considered independently, all of these sources of knowledge have their limitations:

- Geographic variation in natural environmental trends and anthropogenic impacts and a lack of knowledge of the local spatial distribution of ecological systems limits the reliability of applying generic 'expert' knowledge.
- Short term localised scientific monitoring and spatial assessment of the resource fails to take into account temporal variation and is therefore limited to spatial comparisons to assess environmental impacts.
- Local experiential knowledge has the potential to provide information on long term variation in resource condition and use but with limited stakeholder input and without the possibility of verification, information may be subject to significant subjective bias.

The majority of trained personnel in Nicaragua who have access to 'expert' knowledge are located in central government institutions away from the resource and the local stakeholders. It is quite symptomatic for centralised management decisions to be misunderstood and unsupported by local managers and stakeholders who have a good local knowledge of the resource and environmental trends from direct experience [which may not necessarily correlate with expert assumptions].

When combined, 'expert' and 'experiential' knowledge complement each other. The critical point here is that, for the islands environmental management plan to succeed management needs to be integrated with all levels and all sectors of governance and society, who need to be communicating effectively and sharing knowledge. With the current lack of a formal framework for ecological monitoring and of organisation in the fishers groups, incorporation of local knowledge and perceptions is a serious problem which has lead increasingly to a top-down management style from government with subsequent disagreement at the local level.

Without the contribution of local knowledge and monitoring data, ecosystem based coastal resource planning using externally acquired knowledge and generic ecological assumptions requires that decision makers take a precautionary approach. If local knowledge is included and a local participatory monitoring and research programme is initiated a better targeted management plan can be devised which could be inclusive of local stakeholders perceptions. National policies may then start to reflect local concerns more closely. Furthermore, with the contribution of 'expert knowledge' to the local level resource managers could in turn learn from other regional or international successes to help guide local decision making and start to develop tools that can be used to project this knowledge onto individual local level situations.

7.1. PARTICIPATORY GEOGRAPHIC INFORMATION SYSTEMS

With the advent of computer based geographic information systems (GIS) spatial planning of natural resources is rapidly becoming easier, cheaper and more accessible. Almost all coastal environmental and social research has a spatial element and by linking a database to a computer based map almost any kind of information (social and environmental) can be displayed in a simple to interpret and visually appealing format. The maps and data collected during the reefmap study have been collated in an Access database linked to a MapInfo GIS. By overlaying layers such as fishing intensity (collected by interviewing fishers) with the seabed habitat maps it is possible to start to investigate which areas are under greater pressure and therefore enables managers to prioritise efforts and policies..

- **Collecting data on marine ecosystems is expensive and dive surveys of coral reef health may be prohibitively expensive for local NGO's to continue in the short term. This will likely require private sector collaboration with the coasts universities. In the short term the inshore habitat maps can be used to facilitate discussion and the accuracy of these maps would likely be improved by incorporating local knowledge of inshore marine resources from the islands fishers and addition of local names would help to promote local ownership of these maps.**

- **It has become increasingly evident during this study that the wetlands are critical ecosystems and require a collaborative approach to management. These are far more accessible to local researchers and low cost methods of monitoring and research can be employed. Mapping of these habitats with the help of community members and participatory identification of problem sites that could be marked using GPS would be an ideal approach to initial research and would build upon the data recorded during the reefmap study.**

- **The fisheries studies have demonstrated that a great deal of information on the status of the islands terrestrial and offshore coastal ecosystems can be collated from fisher's interviews and if done in a participatory fashion whereby information is collated and fed back to communities this would be an ideal way to start to establish fishers groups in order to facilitate discussion and promote co-management with the central government legislators.**

A great deal of guidance on the use of participatory methods in GIS can be found at www.iapad.org and many of these have been tried and tested around the world. In conclusion participatory GIS provides a ideal way of formalising local perceptions and knowledge in a way that could be contributed to planning and management at government level and as long as the communication is a two way street, this approach would be an ideal step towards a co-management framework.

mindmap **Nicaragua : A PROPOSAL FOR PARCIPATORY ECOLOGICAL MODELLING & MONITORING**

1. PROJECT SUMMARY:

Establishment of a community-based environmental monitoring programme to reduce and prevent negative impacts on wetlands and reefs on the Corn Islands off the Caribbean coast of Nicaragua.

2. OBJECTIVES:

The population of the Corn Islands has quadrupled in the last 20 years, generating an urgent need to formulate and implement an effective coastal management plan for the municipality, ensuring the protection of the ecosystems that uphold the livelihoods and health of the islands' population. Deterioration of mangrove swamps and coral reefs surrounding the islands, not only threatens the sustainability of the lobster fishery and the islands' economy, but also fresh water supply, coastal agricultural productivity and biodiversity.

The *reef***map** project (http://www.reefmap.org.uk) was initiated in May-July2003 and generated groundbreaking information on current ecological and socio-economic conditions of Corn Islands. Threats to coastal ecosystems were revealed, emphasising the urgency of a continuation of the initial project:

- Dumping of waste, sewage and pollutants in wetlands
- Attempts to fill in certain swamps
- Spiny lobster catches plummeting 30% since 2000 due to overfishing
- Large fish becoming scarce in near-shore areas
- Fishers express serious concern that trapping and SCUBA diving (the main fishing techniques) are causing physical destruction of reefs and seagrass beds
- Reef surveys provide evidence for bleaching, white plague disease, and frequent observations of algal overgrowth, which may suggest ecological imbalance, due to insufficient herbivores or eutrophication

This project will build on the initial *reef***map** project, aiding the implementation of local environmental management action plans. A public-private coalition including national environmental and fisheries authorities, regional and local government, NGOs, universities, local enterprises and community representatives, will set up a community-based environmental monitoring programme, find practical solutions to reduce and prevent negative human impact on reefs around the islands, and develop eco-tourism as an ecologically sustainable alternative to the current fisheries overexploitation. A training programme (supported by an international team of ICZM and environmental monitoring specialists) will create local expertise guaranteeing a long-term legacy. Special focus will be directed on:

- Sewage, solid waste and pollution management
- Coastal defences (reefs, beaches, swamps) protection to prevent erosion
- Proposed MPA and wetlands park implementation
- Improved artisanal fisheries regulation
- Ecotourism development
- Public environmental awareness

Once implemented, the Corn Islands reef monitoring and management strategy will not only provide significant improvements in the Islands' environment; it will also provide a framework and knowledge base for addressing other urgent coral reef conservation issues on the Nicaraguan Atlantic Coast.

3. METHODOLOGY:

1. *May2005-January2006.*

- Coalition Workshops set goals and priorities for the project, defining the specific participation of each institution and the format of outputs (e.g. datasystems and reports), allowing integration into the work of the different organisations. The coalition will primarily include Municipal and Regional Government, the Environmental Ministry, the Fisheries Administration, the National

Institute for Territorial Studies, two local Universities and regional and local environmental NGOs.

- Preparation of training programme and data systems (GIS etc.)
- Logistics planning

2. *January2006-May2006.*

- Execution of training programme directed towards staff from local universities, NGOs and authorities. Training will be interactive (using participants' experiences) and supported by appropriate literature (e.g. SocMon, AIMS, and NOAA MPA manuals). It will include:
- Geographic Information System and Database Development
- Local Knowledge/Perceptions/Socio-Economic Mapping and Surveying
- Coastal/Marine Ecological Mapping and Surveying (combining Acoustic-Ground-Discrimination-Systems and satellite imagery, with regionally recognised reef and wetlands survey techniques)
- Pollution Surveying and Wastewater Management
- Data Analysis, Integration and Management Application
- Protected Areas Management
- Eco-tourism
- Environmental education/Participative Research Methods/Public Awareness

Applied survey training will produce environmental assessments providing the base for coastal governance discussions, set-up of a long-term monitoring programme, plans for local environmental management actions, and design, implementation and financing of a local MPA and wetland park. This will be developed in integration with plans for eco-tourism. The importance of public involvement and awareness will be emphasised by integrating a public outreach programme.

*reef***map** is a team of qualified coastal managers with marine biology and social science backgrounds, collaborating with a leading UK-based biodiversity, ICZM and mapping consultancy, Envision, who have successfully conducted training courses to enhance coastal management capacity in Thailand, Malaysia, Nicaragua, Ghana, Nigeria & India. Their extensive expertise and experience combined with strong links to local counterparts provide for a successful outcome of the project.

4. EVALUATION:

Short-term:

- Evidence for course participants' capacity for environmental assessment, monitoring and management planning
- Community-based monitoring programme and field research centre established
- Public participation in the project
- Active coalition partners
- Eco-tourism initiatives
- Plans for environmental action plan implementation

Long-term:

- Continued monitoring
- Environmental action plan implementation based on monitoring data
- Data indicating healthier coastal and marine environments
- Raised public environmental awareness
- Strengthened environmental public-private partnerships
- Established eco-tourism
- Initiation of similar projects in the region

5. FINAL PRODUCT:

- Trained local environmental monitoring team
- Environmental monitoring programme with ca 30 terrestrial and marine survey sites
- Field research station
- Municipal Action Plans for Fisheries Regulation, Solid Wastes, Wastewater and Pollution, Protected Areas and Eco-tourism
- Coastal Environmental Assessment, Monitoring and Management Manual
- GIS and databases integrated into national data systems

- 2 Workshops
- Public Meeting
- Biodiversity Festival
- Newspaper articles and reports for national TV and local radio
- Newsletters circulated locally and internationally
- 6+ papers submitted to peer reviewed journals
- Educational materials for schools, dive centres and others (leaflets, posters and films)
- Established marine and terrestrial nature trails
- Educated local nature guides

Further outputs will depend on local politics and initiatives, and are difficult to quantify at this stage.

6. CONTEXT:

The project is based in a partnership initiated in 2003 between *reef***map**, Envision and the MDDCI (a Corn Islands environmental NGO). Project plans were developed in co-operation with regional NGOs (RAAN-Asdi-RAAS, CBA), local and national authorities, and universities (BICU, URACCAN). It was guided by outcomes from a public meeting and a workshop held in Corn Islands June 2003, where members of civil society, authorities, tourism and dive operators, university staff and students participated.

Development of a coalition of local institutions, organisations and private enterprises, supported logistically by investment in educational, training and research facilities, and financially through eco-tourism and grant funding, ensures a long-term legacy and sustainable financing.

7. INVOLVEMENT AND SUPPORT:

So far we have received widespread support from the project partners in Nicaragua but we are keen to build partnerships and promote collaboration with our Nicarguan Counterparts. If you have any ideas which might help us after reading this document or would like to get involved please email info@reefmap.org.uk or call Duncan on 07796961330.

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