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TOO PRECIOUS TO DRILL: THE MARINE BIODIVERSITY OF BELIZE

Fisheries Centre, University of British Columbia, Canada

TOO PRECIOUS TO DRILL: THE MARINE BIODIVERSITY OF BELIZE

edited by

Maria Lourdes D. Palomares and Daniel Pauly

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CONTENTS

PAGE

DIRECTOR'S FOREWORD 1
EDITOR'S PREFACE 2
INTRODUCTION 3
Offshore oil *vs* 3E's (Environment, Economy and Employment) 3
Frank Gordon Kirkwood and Audrey Matura-Shepherd
The Belize Barrier Reef: a World Heritage Site 8
Janet Gibson
BIODIVERSITY 14
Threats to coastal dolphins from oil exploration, drilling and spills off the coast of Belize 14
Ellen Hines
The fate of manatees in Belize 19
Nicole Auil Gomez
Status and distribution of seabirds in Belize: threats and conservation opportunities 25
H. Lee Jones and Philip Balderamos
Potential threats of marine oil drilling for the seabirds of Belize 34
Michelle Paleczny
The elasmobranchs of Glover's Reef Marine Reserve and other sites in northern and central Belize 38
Demian Chapman, Elizabeth Babcock, Debra Abercrombie, Mark Bond and Ellen Pikitch
Snapper and grouper assemblages of Belize: potential impacts from oil drilling 43
William Heyman
Endemic marine fishes of Belize: evidence of isolation in a unique ecological region 48
Phillip Lobel and Lisa K. Lobel
Functional importance of biodiversity for coral reefs of Belize 52
Janie Wulff
Biodiversity of sponges: Belize and beyond, to the greater Caribbean 57
Maria Cristina Diaz and Klaus Ruetzler
Biodiversity, ecology and biogeography of hydroids (Cnidaria: Hydrozoa) from Belize 66
Lea-Anne Henry
Documenting the marine biodiversity of Belize through FishBase and SeaLifeBase 78
Maria Lourdes D. Palomares and Daniel Pauly
HABITATS 107
Evaluating potential impacts of offshore oil drilling on the ecosystem services of mangroves in Belize 107
Timothy Brook Smith and Nadia Bood
Bacalar Chico Marine Reserve: Ecological status of Belize Barrier Reef's northernmost reserve 112
Mebrahtu Ateweberhan, Jennifer Chapman, Frances Humber, Alasdair Harris and Nick Jones
Preparing for potential impacts of offshore petroleum exploration and development on the marine communities in the Belize Barrier Reef and lagoonal ecosystems 119
Robert Ginsburg
A deep-sea coral 'gateway' in the northwestern Caribbean 120
Lea-Anne Henry
Natural and anthropogenic catastrophe on the Belizean Barrier Reef 125
Richard B. Aronson, Ian G. Macintyre and William F. Precht
Declining reef health calls for stronger protection not additional pollution from offshore oil development 129
Melanie McField

CONTENTS (CONTINUED)

PAGE

FISHERIES AND TOURISM 135
Fisheries based on Belizean biodiversity: why they're so vulnerable to offshore oil exploration 135
Eli Romero and Les Kaufman
Reconstruction of total marine fisheries catches for Belize, 1950-2008 142
Dirk Zeller, Rachel Graham and Sarah Harper
Under the threat of oil: assessing the value and contribution of Belizean fisheries 152
Sarah Harper, Dirk Zeller and U. Rashid Sumaila
The economic value and potential threats to marine ecotourism in Belize 161
Andres M. Cisneros-Montemayor and U. Rashid Sumaila
APPENDICES 167
Conference agenda 167
Letter of scientists to Belizeans 171
Conference participants 172

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DIRECTOR'S FOREWORD

The April 2010 Deepwater Horizon oil rig blowout in the Gulf of Mexico has sharpened attention on the oil spills occurring in many parts of the world ocean, and their potential damaging effects on marine ecosystems and the living organisms they sustain. This report focuses on the sustainability of marine fisheries of Belize in the face of potential impacts of ocean threats – in particular, oil spills. The report is timely and important in at least two ways. First, it addresses oil spills in the ocean, which occur frequently worldwide and can have significant effects on life in the ocean and the wellbeing of the people dependent on it. Second, the report focuses on a small developing country, Belize – an example of a country that does not usually receive the attention it deserves by researchers, even though the ocean and the resources it contains is the main source of existence for its citizens. Thirdly, this work is a collaboration between academic researchers, NGOs and management partners, thereby making the research output more relevant to real life problems.

This report consists of several chapters that tackle issues ranging from the ecology of the marine ecosystem of Belize right through to the economic benefits currently derived from activities dependent on the ecosystem. These include fishing, angling and whale(shark) watching. A crucial point made in the report is that while oil is a non-renewable resource, fish is renewable. This means that in comparing the benefits from drilling the marine ecosystem of Belize, it is important that in the short term, possibly larger benefits from oil drilling should not be allowed to trump benefits that, if well-managed and protected, are capable of continuing to flow through time, benefiting all generations.

The result of the work reported in this contribution, which is based on a broad collaboration between scientists, civil society members and managers, serves as a good example of how to produce policy relevant research that serves societal goals and objectives.

I commend the authors of the report for producing a significant piece of research that has a strong potential to contribute positively to policy making in Belize.

U. RASHID SUMAILA
Director and Professor
The Fisheries Centre, UBC

EDITORS' PREFACE

There is a huge amount of zoological and botanical publications on the marine biodiversity of Belize, notably because the American Museum of Natural History in New York and the Smithsonian Institution in Washington, D.C., established marine stations many years ago in Belize and used these for continuous monitoring, and for generations of graduate students to complete their theses. All these and similar materials were, however, published mainly in US and British scientific journals, with only sporadic efforts to make it accessible to the Belizean students and members of the public. Thus, those Belizeans who live with their back to the sea do not get the information that they need to turn around, and fully appreciate the beauty and wealth of the biodiversity along their shores, and its role in attracting tourists and producing seafood. This also leads to the Belizean public not fully appreciating the risk to marine biodiversity of an oil spill and the potential cost to their economy.

In view of the debate and the possibility of a national referendum on offshore oil drilling in Belize, a conference entitled 'Too Precious to Drill: the Marine Biodiversity of Belize' was organized jointly by Oceana Belize and the *Sea Around Us* project, with major funding from the Oak Foundation. This report assembles the contributions presented at this conference, and is complemented by a conference website ('Too Precious to Drill: the Marine Biodiversity of Belize' at www.seaaroundus.org, under 'Hot Topic') which assembles all the published material that was used in enhancing the content of SeaLifeBase (www.sealifebase.org) and FishBase (www.fishbase.org) for Belize, two global information systems documenting nomenclature, geography, ecology and biology of marine organisms of the world, and which hopefully will become tools for familiarizing Belizean students with their marine biodiversity. Also, we hope that this report and the conference website will contribute to informing the national debate on oil drilling in Belizean waters.

We thank Ms Audrey Matura-Shepherd and her staff at Oceana Belize for their enthusiastic assistance with the preparation of this material and the event at which it was released, and the Oak Foundation for funding the event and the preparation of this report. The *Sea Around Us* project, of which this report is a product, is a scientific collaboration between the University of British Columbia and the Pew Environment Group.

INTRODUCTION

OFFSHORE OIL *VS* 3E'S (ENVIRONMENT, ECONOMY AND EMPLOYMENT)[1]

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ABSTRACT

Belize has a natural resource based economy and its marine resources, particularly the Belize Barrier Reef System and its accompanying Atolls are critical to tourism, Belize's number one foreign exchange earner, act as a natural disaster shield and provide food security, thus being a major source of jobs. Oil concessions have been granted by the Government over most of the offshore waters of Belize, including the Princess acreage with an average water depth of 4,000 ft (1,219 m), but there has been little activity to date. However, as plans move ahead to allow offshore oil exploration and drilling in the precious Belizean waters, it is important to consider the negative impact this will have on the 3E's: Environment, Economy and Employment. Offshore oil is being promoted as an abundant source of revenues and jobs with minimum environmental damage, yet the oil industry experience in other areas of the world and the facts and figures about Belize are saying otherwise. While the onshore oil industry (outside of the national parks) can be beneficial to Belize, the proposed offshore oil industry activity will be potentially damaging to the 3Es and thus, should not be pursued. This applies even if the additional, non-calculable, value that the reefs and atolls provide to the welfare of Belize and that no oil industry can replace, is not taken into account.

INTRODUCTION

Belize has a natural resource based economy and its marine resources, particularly the Belize Barrier Reef System and its accompanying atolls are critical to tourism, are Belize's number one foreign exchange earner, act as a natural disaster shield and provide food security, thus being a major source of jobs. Oil concessions have been granted by the Government over most of the offshore waters of Belize, including the Princess acreage with an average water depth of 4000ft, but there has been little activity to date. However, as plans move ahead to allow offshore oil exploration and drilling in the precious Belizean waters, it is important to consider the negative impact this will have on the 3E's: Environment, Economy and Employment. Offshore oil is being promoted as an abundant source of revenues and jobs with minimum environmental damage, yet the oil industry's experience in other areas of the world and the facts and figures about Belize are saying otherwise.

History of the oil industry in Belize

The first exploration well in Belize was drilled in 1956 by Gulf Oil in the Yalbac area in Cayo District. Between 1956 and 1982, 41 exploration wells were drilled by major oil companies such as Gulf, Philips, Anschutz, Chevron, Esso and Placid. From 1982 to 1997, only nine further exploration wells were drilled by small or independent companies, i.e., Spartan, Central Resources, Lucky Goldstar, Dover and Bright Hawk (Belize Audubon Society, 2008). Onshore and offshore seismic data was acquired during this period over a large area of the country (see Figure 1). Exploration wells drilled in Belize before 1997 found some

[1] Cite as: Kirkwood, F.G., Matura-Shepherd, A., 2011. Offshore oil *vs*. 3E's (Environment, Economy & Employment). *In*: Palomares, M.L.D., Pauly, D. (eds.), *Too Precious to Drill: the Marine Biodiversity of Belize*, pp. 3-7. Fisheries Centre Research Reports 19(6). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

oil, but there were no commercial discoveries, with majority of exploration in shallow waters, except the Gladden #1 well drilled in 1997 at 1,000 ft (304.8 m) water depth (see Figure 2).

In 2000, Belize passed the Petroleum Act into law, which established the framework for opening up the Belize oil industry to new concession holders. Since 2004, 19 new oil concessions have been awarded, mainly to small, newly formed oil companies; 12 concessions are for onshore and 7 are for offshore.

Current onshore oil production

Belize Natural Energy Ltd. made the first commercial oil discovery In the Mike Usher #1 well that was drilled in 2005 in the farming community of Spanish Lookout, between Belmopan and San Ignacio in the Cayo district. This field, for many years the only oilfield producing in Belize, was brought onto production in 2005 and reached a peak production level of 4,500 barrels per day (bpd). All oil produced onshore is exported by road tanker from the field to Big Creek port and then by sea to its point of sale, as there are no oil refining facilities in Belize. Belize Natural Energy ships oil to buyers in Costa Rica, Panama and Corpus Christi, Texas. Some crude oil is also trucked over land to El Salvador. In addition to Spanish Lookout field, the Never Delay field, which extends under Belmopan, was discovered in 2007 and is now under development with a current production rate of about 500 bpd. Figure 3 shows the locations of these onshore oil production sites.

Offshore oil concessions

The oil concession map, as of October 2010, is shown in Figure 4. Offshore concessions are held by 6 companies, these being: Island Oil Belize (since May 25 2004); Miles Tropical Energy Ltd. (12 Oct 2007); PetroBelize Co. Ltd. (12 Oct 2007); Princess Petroleum Ltd. (12 Oct 2007); Providence Energy Ltd. (12 Oct 2007); Sol Oil Belize Ltd. (12 Oct 2007). OPIC Resources Corp., whose concession granted in Jan 2009, withdrew in October 2010. Offshore exploration was limited with: (i) no additional seismic being acquired since 2004 despite commitments to 550 km² by October 2011; (ii) minor relinquishments of acreage by the concessionaires despite 50% relinquishments being due by October 2011; and (iii) 2 offshore wells (one incomplete) being drilled by Island Oil in the south of Belize off Monkey River in 2007.

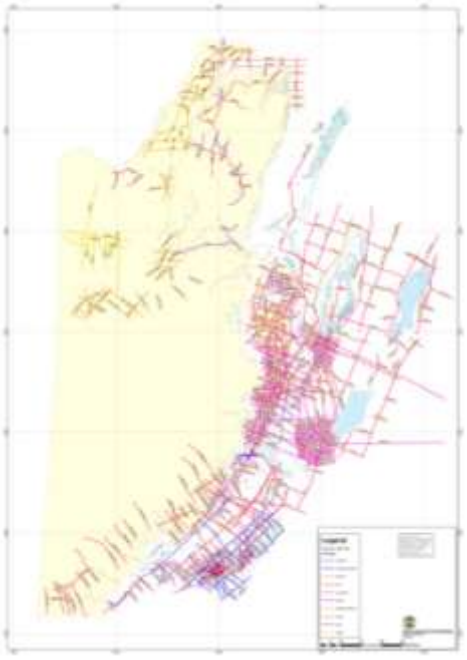

Figure 1. Seismic surveys done in Belize during the period 1955-1997 courtesy of Geology and Petroleum Department, Government of Belize.

Figure 2. Exploration and production wells in Belize from 1955-1997 courtesy of Geology and Petroleum Department, Government of Belize.

IMPACT OF THE OIL INDUSTRY ON THE ENVIRONMENT

There is a potential conflict between the oil industry and the environment both onshore and offshore as the concessions make no special recognition of national parks, marine reserves and other conservation areas as shown in Figure 5. The risks to the environment of offshore oil exploration and development are further increased by a range of factors. The award of deepwater offshore acreage to Princess Petroleum has attracted some criticism. The average water depth in the offshore part of their concession is 4,000 ft (1219 m), with depths ranging from 0 (on Lighthouse Reef Atoll) to 12,000 ft (3658 m) further out to sea. Princess Petroleum Ltd., is a hotel company and had no oil industry experience prior to being awarded this concession, which puts in question their ability to lead successful

and accident-free operations. Moreover, the Belize government lacks the offshore oil industry resources, which, in the event of accidents, prevents immediate intervention. The petroleum Industry in Belize is controlled by the Department of Geology and Petroleum (GPD) within the Ministry of Natural Resources and the Environment (Minister Hon. Gaspar Vega) within the Government of Belize (Prime Minister Hon. Dean Barrow). The GPD department is small, consisting of a Director (Andre Cho) and 6 staff, who not only deal with the oil industry, but with all mineral extraction activities in Belize as well.

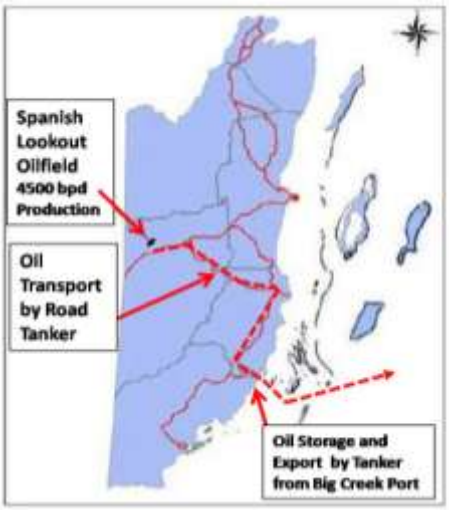

Figure 3. Onshore oil production in Belize as obtained from Belize Natural Energy Ltd.

Belize benefits greatly from its environment. The tourism industry, based on its marine environment, is the country's primary money earner. In addition, the marine environment provides a significant food source for the Belizean people, i.e., fish and crustaceans. And, the barrier reef provides large scale coastal protection for Belize against tropical storms and hurricanes. The current good health of Belize's marine environment is already under threat from a number of sources, and, if offshore oil exploration and development goes ahead, there will be further threats to the environment in terms of: (i) impacts of seismic surveys on fish, mammals and divers; (ii) risk of oil spills, industrial discharges, drilling mud and cuttings discharges from exploration drilling; (iii) dredging, pipelaying, platform and facilities building and installation, large scale well drilling; and (iv) impact of long term industrial discharges into the marine environment.

Figure 4. Map of current petroleum contracts in Belize showing large offshore concessions held by Princess Petroleum Ltd. (in dark violet), which include most of the eastern side of Turneffe Island and the famous dive spot, the Blue Hole (a larger version of this map is reproduced in McField, p. 133, this volume)

THE IMPACT OF THE OIL INDUSTRY ON THE BELIZE ECONOMY

Economic data is scarce for Belize, but according to the CIA World Factbook Data as of June 2011, Belize's GDP for 2010 was 2.651 B USD, which grew by a dismal 2% from the 2009 record, but which saw no growth compared to 2008 with a 3.8 % growth. This is an economy in which the service sector accounts for 54% of GDP, tourism accounting for the largest portion of this sector. With a population of just over 320,000 and a labour force of 130,000, the unemployment rate is a very high at 23% (up from 13.1% in 2009 and 8.2% in 2008), with 43% of Belizeans living below the poverty line. This can easily be appreciated by the fact that exports for 2010 were reported as 404 M USD, while imports were 740 M USD. With this big gap in the balance of payments, external debt is at 1.01 B USD (2009 estimate), and growing. With conflicting reports in the media and some inconsistent data in the CIA World Facts book, we decided to have a look at the economic facts ourselves based on available raw data.

Balance of payments 2011

We looked at the estimated balance of payments for 2011, i.e., a comparison of the amount of money that flows out from a country with the money that flows into a country (see Table 1). This analysis in Belize currency of the expected balance of payments in 2011 shows that there is more money flowing out (1336.3 M BzD) of the economy than there is coming in (1149.6 M BzD). The main foreign currency earners are tourism, onshore oil production and citrus and fruit production. Tourism is Belize's largest economic sector, which for 2011 is expected to account for 565 M BzD.

Table 1. Belize economy, annual gains (In) and expenses (Out) in Million BzD, from major industries based on 2009 and 2011 data projections. This analysis excludes currency movements, including debt repayments and profit repatriation by foreign companies (1 BzD=0.5 USD).

Industry	In	Out	Source
Tourism	565.3	–	World Travel and Tourism Economic Impact Belize (2011)
Petroleum (BNE)	203.8	–	Based on expected BNE production level and average oil price of $87/bbl (2011)
Citrus and fruit	187.3	–	External Trade Bull. (December, 2009), Statist. Inst. Belize
Sugar	89.1	–	Same as above
Fisheries	49.4	–	Same as above
Other exports	54.7	–	Same as above
Machinery and Transportation Equipment	–	266.9	External Trade Bull. (December, 2009), Statist. Inst. Belize
Manufactured goods	–	273.0	Same as above
Mineral fuel and lubes	–	209.5	Same as above
Commercial free zone	–	156.5	Same as above
Food and live animals	–	156.5	Same as above
Chemical products	–	125.2	Same as above
Export processing zone	–	104.9	Same as above
Other imports	–	43.8	Same as above
Total	**1149.6**	**1336.3**	

Impact of onshore oil

Without the impact of offshore oil on the 3Es, i.e., just relying on onshore oil, it is expected that in the next decade (starting in 2021), the amount of money flowing into Belize will drastically increase to $2370 M BzD with tourism accounting for almost 50% of this, and the onshore oil industry contributing 13%, with the declining contribution on BNE being replaced by revenue from oil fields resulting from the treaty energy work for Princess Petroleum Company (under their option agreement), assuming they make the finds that treaty are targeting in the Princess onshore acreage in the south of Belize.

Figure 5. Concession areas in Belize include 53 defined terrestrial and marine protected areas. Adapted from the newspaper Amandala, 26/1/2011.

Impact of offshore oil

But if offshore oil exploration goes ahead and results in discoveries in line with government expectations, production could be started by 2018, and by 2021 offshore oil could account for 70% of revenues to economy (not accounting for the portion of the oil revenues flowing out of the country as investors transfer profits to their foreign accounts). However, due to the risk of offshore oil damaging the marine environment, offshore oil would most likely result in a decline in the tourism and fisheries.

THE IMPACT OF THE OIL INDUSTRY ON EMPLOYMENT

Jobs picture in 2011

Employment data are even scarcer for Belize than economic data. However, the Figure 6A shows our best estimate of the jobs picture in 2011, by industry.

Forecasted jobs picture in 2021 with onshore oil only

With onshore oil only, by 2021 the employment picture in Belize would be much better than today (see Figure 6B). With growth in tourism and fisheries (and other economic sectors) and some additional jobs in the onshore oil industry that could be filled by Belizean workers, as Belize Natural Energy Ltd have already proved. For example, in the tourism industry, jobs are expected to grow from 39,000 in 2011 to 61,000 jobs by 2021 (i.e., almost 40% of the workforce).

Forecasted jobs picture in 2021 with onshore and offshore oil

The concern is that while it appears there would be more money in the economy with offshore oil, the impact on jobs will not be good, because (unlike the onshore oil industry) the environmental risks from the offshore oil industry in Belize would make a significant percentage of a large number of people who work in the tourism and fisheries industries unemployed (see Figure 6C). While the jobs created by the offshore oil industry will not be sufficient to replace these jobs. In addition because of the expertise, skills and experience these jobs require they will largely have to be filled by foreign experts who have the qualifications and offshore experience in other locations.

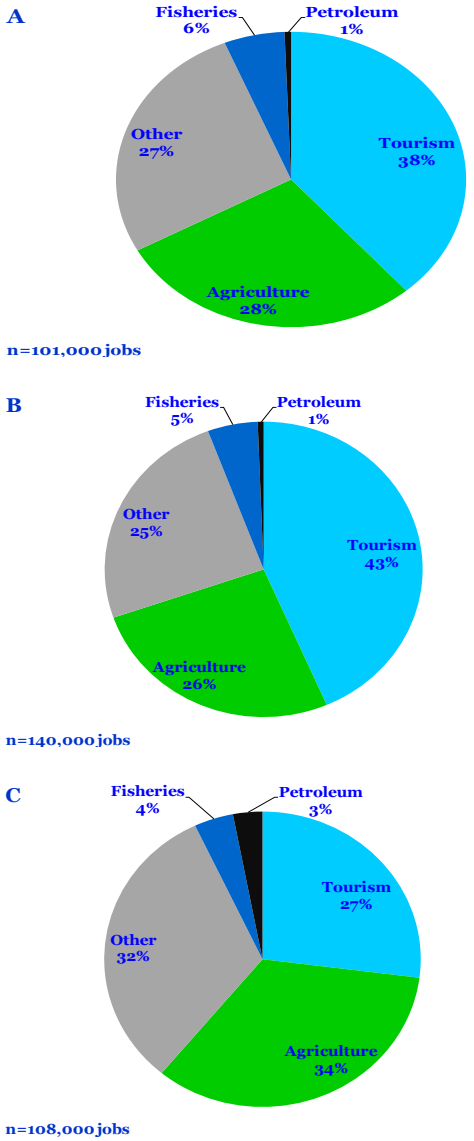

Figure 6. Employment picture in Belize estimated by economic sector, but excluding the 2011 unemployment level of 23% (i.e., 29,900 unemployed workers). A: Employment in 2011. B: Predicted employment levels in 2021 without employment by the offshore oil industry. C: Predicted employment levels in 2021 including employment by the offshore oil industry.

CONCLUSIONS

Thus, it can be concluded that while the onshore oil industry (outside of the national parks) can be beneficial to Belize, the proposed offshore oil industry activity will be potentially damaging to the 3Es, "Environment, the Economy and Employment", and so should not go ahead. There is an additional non-calculable value that the reefs and atolls provide to the economy and welfare of Belize that no oil industry can replace. It should be noted that while petroleum is finite, the benefits of the reef should be infinite if used sustainably.

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THE BELIZE BARRIER REEF: A WORLD HERITAGE SITE[1]

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ABSTRACT

The Belize Barrier Reef Reserve System (BBRRS) World Heritage Site was declared by UNESCO in 1996 as a serial nomination composed of seven marine protected areas that represent the largest barrier reef system in the Western Hemisphere. The criteria for the listing of the BBRRS were its superlative natural phenomena and natural beauty, ongoing biological and ecological processes, and biological diversity, including several threatened species. The BBRRS has one of the highest levels of marine diversity in the Atlantic. In 2009, the Site was inscribed on the List of World Heritage in Danger for several reasons: the sale and lease of public lands within the property, destruction of fragile ecosystems due to resort and housing development, and the impact of introduced species. An additional conservation issue of concern noted was the granting of offshore oil concessions. With the prospect of offshore oil exploration and drilling added to the existing threats to the Site, particularly to its coral reefs in this era of climate change, its future integrity is at risk. In addition to the value of the BBRRS in terms of tourism and recreation, fisheries, shoreline protection and other potential economic benefits, the World Heritage Site is a source of immense national pride, as the Belize Barrier Reef is emblematic of Belize's outstanding heritage of marine biodiversity.

INTRODUCTION

Prior to the inscription of the Belize Barrier Reef Reserve System as a natural World Heritage Site in November 1996 (UNESCO, 1996), the Belize barrier reef was under consideration for this designation for many years. At a workshop held in 1993, Belize decided to submit a serial nomination. Under the leadership of the GEF/UNDP project on 'Sustainable Development and Management of Biological Diverse Coastal Resources', the nomination document was prepared in 1995 and submitted formally to the World Heritage Centre by the government of Belize. In January 1996, IUCN conducted a site visit of the protected areas proposed in the nomination. At the time, three of the marine reserves to be included had not yet been established, namely the Sapodilla Cayes and South Water Caye Marine Reserves, and Bacalar Chico National Park and Marine Reserve. These three protected areas, however, were then legally declared in mid 1996. The Hol Chan Marine Reserve was also included in the original proposal, but IUCN felt that it was too small an area and did not add significantly to the nomination and recommended in particular that the Blue Hole on Lighthouse Reef should be included in the nomination, due to its unique geological formation. The review (IUCN, 1996) also mentioned that the serial nomination did not include a complete cross-section of all the elements of the system (for example the Turneffe Islands), but noted these could be added at a later phase. In view of this, the Blue Hole Natural Monument was also declared a protected area in 1996, and replaced the Hol Chan Marine Reserve in the final nomination. Another concern was in relation to the need for a wider management regime to ensure the integrity of the proposed Site. This was addressed by the explanation that Belize was committed to establishing a Coastal Zone Management Authority, which would prepare a National Coastal Zone Management Plan that would provide the necessary management controls. The World Heritage Centre had a few additional queries on the submission, including a concern about future offshore oil exploration. The government provided a statement of explanation on the nature, extent and controls applying to exploratory oil drilling offshore, such as the need to go through an Environmental Impact Assessment process. With these concerns addressed, the inscription of the Belize Barrier Reef Reserve System as a World Heritage Site proceeded at the 20th ordinary session of the World Heritage Committee held in Merida, Mexico on the 2 to 7 December

[1] Cite as: Gibson, J., 2011. The Belize Barrier Reef: a World Heritage Site. *In*: Palomares, M.L.D., Pauly, D. (eds.), *Too Precious to Drill: the Marine Biodiversity of Belize*, pp. 8-13. Fisheries Centre Research Reports 19(6). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

1996. It was inscribed under the natural criteria (ii) superlative natural phenomena and natural beauty, (iii) ongoing biological and ecological processes, and (iv) biological diversity, including several threatened species, as the largest reef in the Northern Hemisphere, and as a serial nomination consisting of seven protected areas (UNESCO, 1996) covering an area of 96,300 ha (IUCN, 1996).

The Belize Barrier Reef system is unique for its size and array of reef types within one relatively self-contained area. It encompasses a 220 km long barrier reef, three offshore atolls, numerous patch reefs, complex mazes of faro reefs, fringing reefs, and large offshore mangrove cayes (IUCN/UNEP, 1988) all of which are represented within the World Heritage Site. In 1842, Charles Darwin referred to it as the 'the most remarkable reef in the West Indies' in his book entitled *The Structure and Distribution of Coral Reefs*. This highly diverse system includes at least 61 coral species (Fenner, 1999), with at least 343 additional marine invertebrate species (Jacobs and Castaneda, 1998), over 500 species of fish, 45 hydroids, 350 molluscs (IUCN, 1996), and at least 70 species of ascidians, including an endemic species (Goodbody, 2000). Threatened or endangered species include staghorn coral *Acropora cervicornis* and elkhorn coral *Acropora palmata*, three species of marine turtles (hawksbill *Eretmochelys imbricata*, loggerhead *Caretta caretta* and green turtles *Chelonia mydas*), the American crocodile *Crocodylus acutus*, the great hammerhead shark *Sphyrna mokarran*, goliath grouper *Epinephelus itajara*, Nassau grouper *Epinephelus striatus*, and the West Indian manatee *Trichechus manatus manatus*.

The Belize National Biodiversity Strategy states that Belizeans, along with their global partners, are dependent on biodiversity and have a responsibility to contribute towards its conservation (Jacobs and Castaneda, 1998). Indeed, IUCN noted that the history of the Belize Barrier Reef Complex illustrates the major role that reefs have played in the history of humankind, as in Belize today a large part of the economy is dependent on the reef through fisheries and tourism (IUCN, 1996).

Results and Discussion

The seven protected areas that comprise the World Heritage Site are: Bacalar Chico National Park and Marine Reserve, Blue Hole Natural Monument, Half Moon Caye Natural Monument, Glover's Reef Marine Reserve, South Water Caye Marine Reserve, Laughing Bird Caye National Park, and the Sapodilla Cayes Marine Reserve (see Figure 1). The marine reserves were established under the Fisheries Act and the natural monuments and national parks were declared under the National Parks Act. Four of the protected areas are presently managed under co-management agreements between national conservation non-government organizations and the Fisheries or Forest Departments.

Bacalar Chico National Park and Marine Reserve: This protected area is located on the northern end of Ambergris Caye, on the border with Mexico. The reef is representative of the northern province (Burke, 1982), and is characterized by the unusual formation of a double reef crest. A multi-species fish spawning ground is located at the reef promontory of Rocky Point, where a queen conch *Strombus gigas* spawning area is also located. The barrier reef also touches the shore at Rocky Point, where outcrops of Pleistocene fossilized reefs are exposed. The terrestrial component includes lagoons, salt marsh, mangroves, unique vegetation types (e.g., the kuka palm, *Pseudophoenix sargentii*) and some of the best littoral forest in Belize, recognized as the most threatened and under-represented ecosystem in the country (Wildtracks, 2010). The eastern beach is a nesting site for loggerhead, green and hawksbill sea turtles and the forests and wetlands support a diverse wildlife of waterbirds, a number of Yucatan endemic birds such as the Yucatan jay *Cyanocorax yucatanicus* and the orange oriole *Icterus auratus*, 36 species of reptiles including the American crocodile, and at least 31 mammals, including several species of wild cat, such as the jaguar *Panthera onca*. Manatees inhabit the lagoon west of the caye.

Blue Hole Natural Monument: This site is a hallmark of Belize and is famous for its unique formation and geological history. Located on Lighthouse Reef Atoll, it is a circular submerged collapsed cave or sinkhole. Such cave systems formed on the offshore limestone platforms during the Pleistocene lowering of sea levels. The rim of the hole has lush coral growth, and 24 species of coral have been noted (Graham *et al.*, 2005). The 125 m deep hole has many large stalactites (Dill, 1971) The Blue Hole is visited by great hammerhead sharks, an endangered species, as well as lemon, bull and black tip sharks (Graham *et al.*, 2005). Kramer and Kramer (2000) highlighted the potential of unique assemblages of cryptic and endemic species occurring in this underwater cave system.

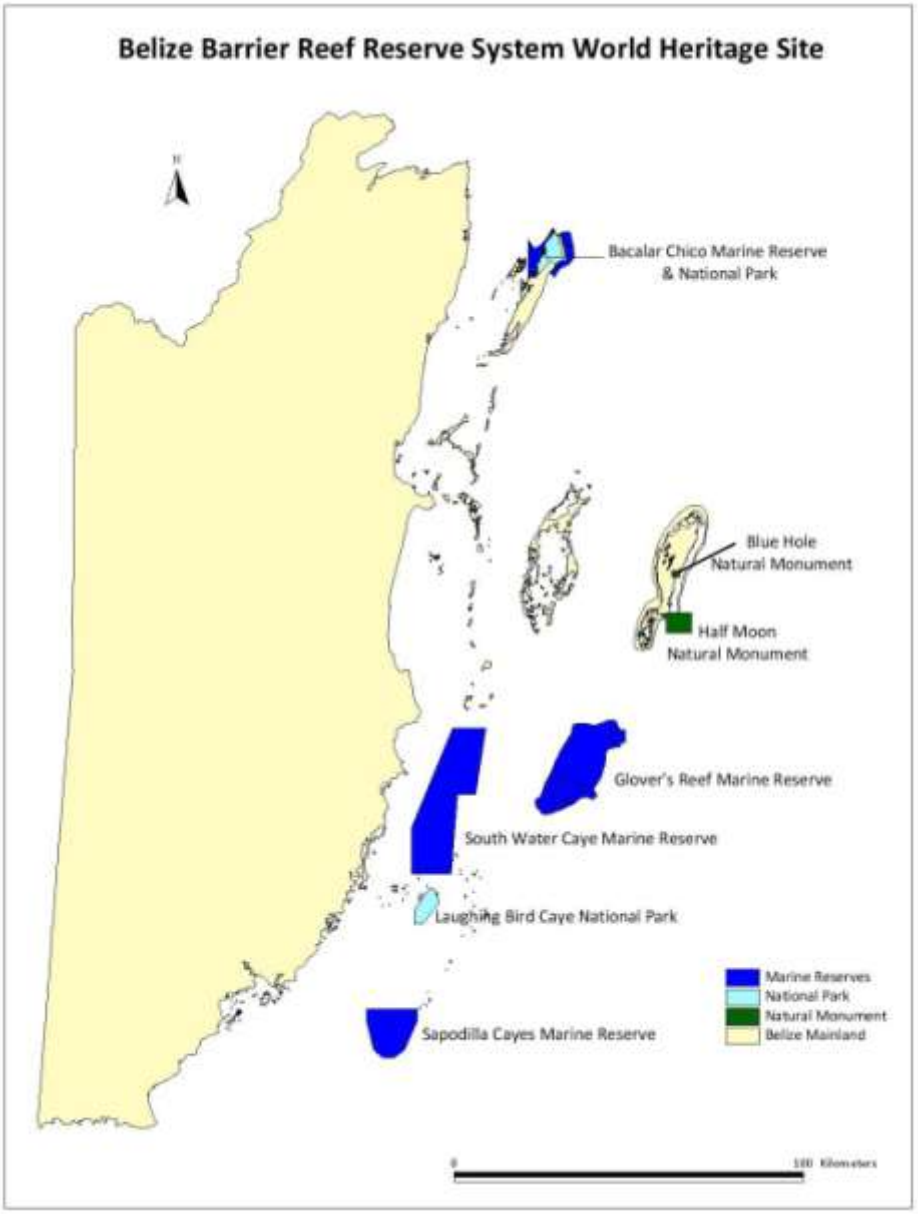

Figure 1. Map showing the seven protected areas comprising the World Heritage Site

Half Moon Caye Natural Monument: This protected area is also located on Lighthouse Reef Atoll and includes Half Moon Caye and the surrounding atoll fringing reef and lagoon. The caye supports climax littoral forest that provides one of only two nesting sites in the Caribbean for the white color phase of the red-footed booby, *Sula sula*. The island is an important nesting site for frigate birds, and loggerhead, green and hawksbill sea turtles. The endemic island leaf-toed gecko *Phyllodactylus insularis*, and Allison's anole *Anolis allisoni* are also found on the caye. The natural monument is noted for its steep fore-reef wall dropping to over 3,000 feet (>914 m) where the greatest diversity of reef fish occurs (Graham *et al.*, 2005), and it includes a reef fish spawning site. Forty-five species of coral have been documented in the protected area (Graham *et al.*, 2005).

Glover's Reef Marine Reserve: This reserve encompasses the entire Glover's Reef Atoll, which is the southernmost of Belize's three offshore atolls. Glover's Reef is considered the prototypic atoll of the Caribbean; it is not only the best developed biologically, but also possesses the greatest diversity of reef types (Dahl *et al.*, 1974). Its deep lagoon is studded with over 800 patch reefs and pinnacles. Forty-five species of corals have been documented for the atoll (Bright and Lang, 2011). The northeastern corner of

the atoll is the site of one of the largest and last remaining Nassau grouper aggregations, which is also an aggregating site for more than 20 other reef fish species (Sala *et al*., 2001). All three species of marine turtles—loggerhead, green and hawksbill—occur on the atoll, which is an important foraging area for these reptiles, particularly the hawksbill turtle (Coleman, 2010). The endemic island leaf-toed gecko also occurs at Glover's (Wildtracks and Wildlife Conservation Society, 2007).

South Water Caye Marine Reserve: The largest of the protected areas in the World Heritage Site, this reserve includes a portion of the barrier reef that is representative of the central province (Burke, 1982), characterized by well-developed reefs, such as the 9 km unbroken well-developed reef tract of Tobacco Reef with its extensive spur-and-groove system. It also includes several unique rhomboid or faro reefs, such as the Pelican Cayes, which are atolls situated on the continental shelf. The Pelican Cayes depict an unusual juxtaposition of fragile reef and mangrove communities and are considered a marine biodiversity hotspot, due to the extraordinary high diversity of sponges and tunicates on the mangrove roots and in the lagoons of the faro that is unparalleled in the Caribbean (Goodbody, 1995). For example, 70 species of ascidians or tunicates have been recorded from the area, including an endemic species (Goodbody, 2000), 31 species of bryozoans (Winston, 2007) 52 species of echinoderms, (Hendler and Pawson, 2000), 7 species of Foraminifera that include two new species (Richardson, 2000), 147 species of sponges, 45% of which are new species or variants (Rützler *et al*., 2000) and 148 species of algae (Littler *et al*., 1985). The reserve also provides habitat for American crocodiles, manatees, and sea turtles. South Water Caye Marine Reserve has many large offshore mangrove cayes or ranges that provide nesting habitat for brown boobies *Sula leucogaster* and frigate birds *Fregata magnificens*. The sand cayes are nesting sites for several tern species, including bridled terns *Sterna anaethetus*, least terns *S. antillarum* and roseate terns *S. dougalli* (Wildtracks, 2010).

Laughing Bird Caye National Park: The National Park encompasses the entire Laughing Bird Caye faro reef, which encloses a spectacularly pinnacled lagoon and is considered one of the best examples of faro formation in the Caribbean (Wildtracks, 2010). The outer sides of the faro drop steeply to about 100 feet (30 m) to the deep channels surrounding the shelf atoll, including the Victoria Channel. The faro lagoon is noted as an important habitat for adult conch *Strombus gigas*, a species that is listed under Appendix II of CITES. The long narrow sand and shingle caye lies on the steep side of the faro, and is named for the laughing gull *Larus artricilla* that used to nest on the island. It is an important nesting ground for the hawksbill turtle.

Sapodilla Cayes Marine Reserve: The reefs of the Sapodilla Cayes Marine Reserve are located at the southern end of the barrier reef, forming a unique hook-shaped structure (Kramer and Kramer, 2000). They are representative of the discontinuous reefs of the southern province of the barrier reef (Burke 1982) and have extensive spur-and-groove formations extending eastward. The reserve has the highest coral diversity in Belize (Wildtracks, 2010) and includes three fish aggregating sites, at Nicholas Caye, Rise and Fall Bank, and Seal Caye, all important for the endangered Nassau grouper and other reef fish. The reserve encompasses 14 sand and mangrove cayes. Hunting Caye is a nesting site for the highly endangered hawksbill turtle.

As the Belize Barrier Reef Reserve System is a serial nomination, other protected areas can be added to the World Heritage Site, and recommendations have been made to include the Gladden Spit and Silk Cayes Marine Reserve and the Port Honduras Marine Reserve. Progress on nominating these additional areas, however, has been delayed due to the recent inscription of the Site on the List of World Heritage in Danger in June 2009 (UNESCO World Heritage Committee - Decision - 33 COM 7B.33).

In 2008, concerns were reported to the World Heritage Centre regarding extensive mangrove cutting, dredging and infilling in the Pelican Cayes region of the South Water Caye Marine Reserve. In addition, news of an impending sale of 3,000 ha of land in the Bacalar Chico National Park also raised concerns, although plans for the sale were later cancelled (UNESCO World Heritage Committee - 08/32.COM/7B). As a result of these concerns, a mission from the World Heritage Centre visited Belize in March 2009 to assess the status of the Site. The report on the mission noted (UNESCO WHC - 09/33.COM/7B.Add), *inter alia*, that several dozen transfers of public lands were made for development purposes since the original inscription of the Site in 1996 and as a result the Outstanding Universal Value had been affected by this ongoing development on the cayes. It also noted that the Coastal Zone Management Authority and Institute were not able to carry out their mandate and that there was poor coordination between the government agencies responsible for overall management of the World Heritage Site. Other concerns

included illegal fishing, particularly within the no-take zones, and potential impacts by introduced invasive species. The report highlighted the corrective measures that Belize needed to implement. In August 2010, the World Heritage Committee decided to retain the Belize Barrier Reef Reserve System on the List of World Heritage in Danger (UNESCO World Heritage Committee - Decision - 34 COM 7A.13). The main concern noted as part of this decision was in relation to oil concessions reportedly granted within the marine area of the property, as oil exploration is considered incompatible with World Heritage status, and Belize was urged to enact legislation to prohibit oil exploration within the Site.

More than 75% of coral reefs in the Caribbean are considered threatened (Burke *et al.*, 2011). Climate-related threats are expected to increase the proportion of reefs at risk to 90% in 2030 and up to 100% by 2050 (Burke *et al.*, 2011). The recent report card on the health of Belize's reefs showed that 65% of the reef is rated as being in poor or critical health, with only 1% considered in very good health (Healthy Reefs, 2010). It is clear that the threats to Belize's reefs need to be reduced in order to promote their recovery. Offshore exploration for oil, however, will increase the threats to the reef system. Shallow coral reefs, seagrass beds and mangroves, which characterize the Belize Barrier Reef Reserve System, are among the most sensitive environments to oil, with mangroves being the most susceptible (Guzman *et al.*, 1991). Furthermore, it is difficult to carry out any oil spill mitigation measures for these habitats.

Finally, the Belize Barrier Reef Reserve System is representative of Belize's marine system, which has been valued at 231-347 M USD year^{-1} in terms of the contribution of the coral reefs and mangroves to shoreline protection, tourism and fisheries (Cooper *et al.*, 2009). Loss or damage to these critical ecosystems will result in a decline in the valuable services they provide to the country. Importantly, a recent study has shown that biodiversity losses due to human disturbance are raising concerns about the future functioning of ecosystems and their ability to deliver goods and services to humanity. For example, reef fish systems function better in terms of standing biomass with the addition of species or increased diversity (Mora *et al.*, 2011). Thus the consequences of losing biodiversity are even greater than previously thought and could be devastating for coral reef fisheries. All efforts should be made to protect the biodiversity of the Belize Barrier Reef Reserve System World Heritage Site, as it is integrally connected to the human development and national heritage of Belize.

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BIODIVERSITY

THREATS TO COASTAL DOLPHINS FROM OIL EXPLORATION, DRILLING AND SPILLS OFF THE COAST OF BELIZE[1]

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ABSTRACT

Protected from import/export, wildlife trade, and hunting by Belize's 1981 Wildlife Protection Act, threats from human induced mortality to coastal dolphins are currently minimal. Dolphins along the coast, islands and offshore areas of Belize are distributed in small, thus vulnerable population groups. Currently, unsustainable fishing (overfishing and illegal fishing) causing prey depletion and indirect capture, rapid coastal development (mangrove clearing, dredging, and coastal development), increasing vessel traffic and pollution have been identified as growing threats as human populations and coastal use grow. However, oil exploration, drilling and the possibility of spills off the coast of Belize are additional threats. The increases in shipping due to oil and gas exploration are likely to lead to acoustic disturbances and ship strikes for Belizean dolphins. Seafloor exploration for oil resources involves seismic testing. The loud, broad band sounds produced by seismic air guns have been shown to cause avoidance and other behavioural responses in beluga whales and other odontocete (toothed) species, which could lead to long-term adverse effects on populations. Seismic impulses can travel for long distances, and in some cases have been detected over 3000 km from their source. While the effects of air gun noise vary, other observed effects include auditory damage and decompression sickness. Seismic airguns may also affect prey including fish and squid. During drilling and production, populations of dolphins would be vulnerable to the cumulative effects of chronic oil pollution from small tanker spills, pipeline leaks and other accidents. A catastrophic oil spill would be extremely harmful. While cetaceans are less vulnerable to oiling than many other marine species such as otters and seabirds, oil may damage the eyes, and inhalation of surface vapours can damage their lungs. Also, oil spills may have long-term impacts on prey populations such as fish and benthic invertebrates.

INTRODUCTION

Protected from import/export, wildlife trade, and hunting by Belize's 1981 Wildlife Protection Act, threats from human induced mortality to coastal dolphins are currently minimal. Dolphins along the coast, islands and offshore areas of Belize are distributed in small, thus vulnerable population groups. Currently, unsustainable fishing (overfishing and illegal fishing) causing prey depletion and indirect capture, rapid coastal development (mangrove clearing, dredging, and overdevelopment), increasing vessel traffic and pollution have been identified as growing threats as human populations and coastal development increase. As the possibility of off-shore oil drilling in Belize is explored, research results and recommendations as to the effects of petroleum development need to be heeded. Threats to Belize's dolphins can be identified in all stages of offshore petroleum industry activities: exploration, production, transportation and accidents.

There are two species of dolphins found along the coast of Belize: bottlenose (*Tursiops truncatus*) and rough-toothed (*Steno bredanensis)*, bottlenose being the most predominant. The IUCN does not currently list a population estimation for bottlenose dolphins in the Caribbean (Hammond *et al*., 2008a). Although considered a species of 'least concern' internationally, specific demographic information about bottlenose

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dolphins in Belize has not been established. While projects have been conducted since 1992 on various topics, research has not been country-wide. We cannot estimate the number of animals within Belize as a whole, or clarify dolphin movements and home ranges.

Research on bottlenose dolphins has led scientists to consider them as inhabitants of distinct long-term stocks. For instance, there are 32 provisionally identified stocks or communities identified in the Gulf of Mexico, based on geographic, genetic and social relationships (Waring *et al.*, 2009; Wells *et al.*, 1987). While these communities are not closed demographic populations, as there is known interbreeding with adjacent communities, residents interact with each other, share habitat areas, and have similar distinct genetic profiles. These communities have multi-year, multi-generational patterns within a geographic area such that the dolphins are considered integral units within the ecosystems they inhabit. Thus, if the home range of such a community were eradicated or severely disturbed, it would take a long time to repopulate the dolphin population and resulting effects of this on local ecology is unknown. Also, bottlenose dolphins are known to be predominantly coastal. They have been seen in pelagic areas, and classified as either coastal or offshore, with varying foraging behavior. Offshore animals have been seen as residents on offshore islands, which is relevant to the outer atolls of Belize (Wells and Scott, 1999). Without concrete data to support large-scale management, it is more appropriate to consider a precautionary approach to conservation-oriented management at the community or stock level.

Rough-toothed dolphins are found globally in tropical to subtropical oceans in both oceanic and deeper continental shelf waters (Hammond *et al.*, 2008b). Limited survey efforts have been conducted in the U.S. Gulf of Mexico (although recent status reports cautiously estimate 2,653 animals). No formal surveys have been conducted in the Caribbean which leaves no information or current population estimate for Belizean waters. As there is no recorded major human disturbance currently, the dolphin is not on the U.S. endangered species list and is considered a species of least concern globally on the IUCN Red List (IUCN, 2011). However, there are insufficient data from which to determine population trends for this species (Waring, 2009). While rough-toothed dolphins are not seen in the same structured communities as bottlenose dolphins, lack of knowledge of their regional numbers, distribution and habitat use should be considered cause for risk-averse management.

Figure 1. The Drowned Cayes and Turneffe Atoll (adapted from belizetravelmall.com).

Dolphins in Belize

Bottlenose dolphins in Belize have primarily been studied in the Drowned Cayes and Turneffe Atoll (Figure 1). Both sites have dolphins present year-round within the unique and highly productive combination of mangrove, seagrass and coral habitats.

Drowned Cayes

The latest information on bottlenose dolphin research in the Drowned Cayes is from Kerr *et al.*, (2005). This paper documents photo-identification research between 1997-1999. The authors estimated the 122 (95% CI = 114 -140) animals there as a closed population. When comparing this population with research at Turneffe Atoll, they noted similar small group sizes, variable levels of site fidelity and low abundance, but did not find any overlap in sightings. Kerr *et al.*, (2005) noted the proximity of the Drowned Cayes to mainland Belize, exposing the dolphins to increased risks of pollution, boat traffic, resource extraction and

increasing levels of fishing extraction. They mentioned that research has noted that long-term overfishing of Caribbean reefs has already affected fish community structures and coral ecosystems (Sedberry *et al.*, 1999; Jackson *et al.*, 2001).

Turneffe Atoll

Turneffe Atoll is relatively pristine, further from the coastal development of mainland Belize, with few year-round inhabitants. However, increasing development due to ease of access since an airstrip was built in 2004, and the expansion of tourism and cruise ship visits are unaddressed threats. Various researchers, since 1992, have studied the Atoll's dolphins (a summary of Turneffe Atoll dolphin research can be found in Dick, 2008). Relevant here are results that showed a combination of continuous and seasonal residents with an estimated population of 216 dolphins (CV = 27.7%), with most sightings in channels between mangroves and reefs, and a relatively large seasonal population of mothers and calves (Grigg and Markowitz, 1997; Grigg, 1998; Dick and Hines, 2011). Threats to dolphins noted here include unsustainable fishing and illegal gillnetting by Guatemalan and Honduran fishers. Dredging of mangrove and seagrass for development can impact local fish and trophic levels (Dick and Hines, 2011).

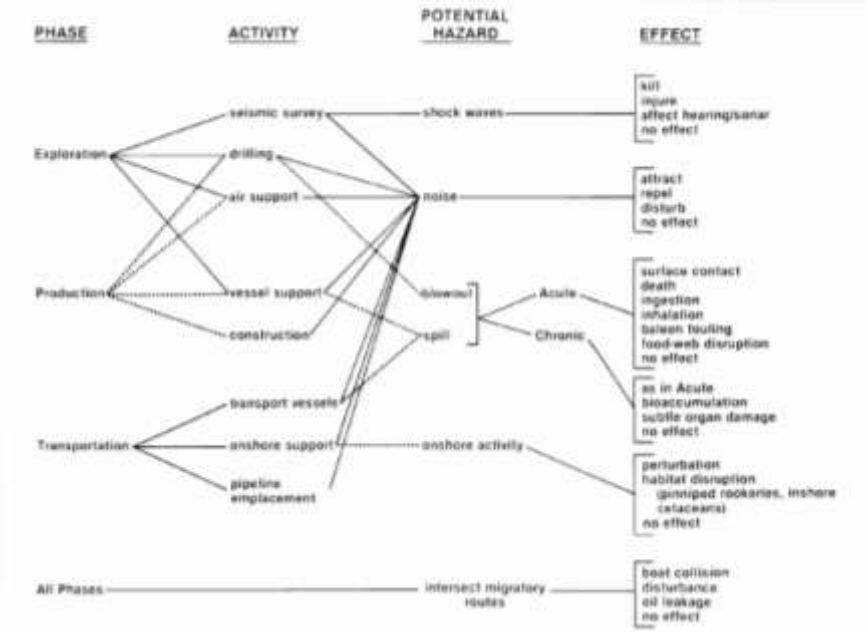

Figure 2. Proximate factors associated with offshore oil exploration and their effects on marine mammals (Geraci and St.Aubin, 1980).

Threats

Offshore oil activities can be threatening to marine mammals in various ways. Habitats can be altered and behavior disturbed by noise from seismic surveys, shipping and drilling. Related pollutants can be chronically released, and there is a real risk of an accidental oil spill from platforms and tankers. As oil activities grow, they can create cumulative impacts on near and offshore ecosystems. As oil tanker traffic increases, the chances for shipboard spills and collisions increase as well (Huntington, 2009). As shown in Figure 2, each phase of the offshore oil activity listed has its own potential threats. Note that noise as a potential hazard is associated with each listed activity: seismic surveying, drilling, air and ship support, construction and operation (Geraci and St. Aubin, 1980).

Exploration

Seafloor exploration for oil resources involves increases in shipping, which generate their own noise and dangers of collision with dolphins. However, seismic testing associated with offshore oil exploration is one of the most intense anthropogenic noises in the ocean and often are implemented over large areas for extended periods (Gordon *et al.*, 2003). The loud, broad-band sounds produced by seismic air guns have been shown to cause avoidance and other behavioral responses in beluga whales and other odontocete (toothed) species, which could lead to long-term adverse effects on populations. Seismic impulses can travel for long distances, and in some cases have been detected over 3000 km from their source. While the effects of air gun noise vary, other observed effects include auditory damage and decompression sickness. Seismic airguns may also affect prey including fish and squid. And while these are problematic, seismic surveys are only one element of the noise contribution of exploration. Field development and construction,

exploratory drilling, underwater acoustic communication, equipment placement, and sea-floor processing all generate their own particular noises (Fernández *et al.*, 2004; Gordon *et al.*, 2003; Geraci and St. Aubin, 1980; M. Stocker, 2011, pers.comm.). While most of the sound of the seismic air guns is around 100 Hz, there is leakage of sounds at higher frequencies (around 200-500 Hz), closer to the hearing range of odontocetes (between 200 Hz and 100 kHz; Ketten, 1998), that are audible between 10 to 100km. Dolphins have been observed both less frequently and not vocalizing as usual during seismic surveys (Harwood and Wilson, 2001). The potential effects of low-frequency sounds on marine mammals as assessed by the U.S. Marine Mammal Commission (Anon., 1998) includes, in decreasing order of severity:

- Death from lung hemorrhage or other tissue trauma;
- Permanent or temporary hearing loss or impairment;
- Disruption of feeding, breeding, nursing, acoustic communication and sensing, or other vital behavior. If severe, frequent or long lasting this could lead to a decrease in individual survival and productivity and a corresponding decrease in population size and productivity;
- Abandonment or avoidance of traditional feeding, breeding or other biologically important habitats, again with possible effects on survival, productivity and population size;
- Psychological and physiological stress making animals more vulnerable to disease, parasites and predators;
- Changes in the distribution, abundance or productivity of important marine mammal prey species with consequent effects on individual survival, productivity and population size.

Production and transportation

During drilling and production, populations of dolphins would be vulnerable to the cumulative effects of chronic oil pollution from small tanker spills, pipeline leaks and other accidents. There are increased risks of ship collisions. As seen in Figure 2, noise from drilling is also present. Ships employed in transportation of oil products and movement of materials and personnel are of varied sizes, but can be responsible for underwater noise that can spread from dozens to hundreds of kilometers. Larger ships generate more low-frequency sounds that are less dangerous to small cetaceans such as dolphins, however, Würsig and Greene (2002) studied the effects of small and medium tankers in Hong Kong on small local cetaceans and found that noise from these vessels could interfere with passive listening for prey, and possibly communication. Results also suggested possibilities for increased stress or permanent shifts in hearing levels.

Accidents

A catastrophic oil spill would be extremely harmful. Ninety-two percent of dolphins found in the oiled areas within a year of the Deepwater Horizon BP oil spill were dead (NOAA, 2011). Marine mammals such as dolphins and whales must come to the surface to breathe; inhaling spilled petroleum products can expose them to floating oil. Ingested oil can kill animals immediately; more often it results in lung hemorrhaging, liver, and kidney damage which can lead to death. Oil accumulated on the skin of animals can make it difficult to breathe and move in the water. While cetaceans, with their smoother skin, are less vulnerable to oiling than many other marine species such as otters and seabirds, oil may damage the eyes. Oil spills may also have long-term impacts on prey populations such as fish and benthic invertebrates (Geraci and St. Aubin, 1980; IWC, 2010).

DISCUSSION

Dolphins in Belize are already exposed to the cumulative effect of unsustainable fishing (over fishing and illegal fishing) causing prey depletion and indirect capture, rapid coastal development (mangrove clearing, dredging, and overdevelopment), increasing vessel traffic and pollution have been identified as growing threats as human populations and coastal use grow. While there is more information about bottlenose than rough-toothed dolphins, both species are found in small population groups, susceptible to loss of animals. Mother and calf pairs of bottlenose dolphins found seasonally (see above) in Turneffe Atoll could be especially vulnerable. Habitat destruction would damage the structure of bottlenose dolphin population communities which would increase recovery time and amplify disturbance to local trophic systems. Oil exploration, drilling and the possibility of spills off the coast of Belize are a quite severe danger to small

cetaceans. Toxicity as a result of oil spill accidents, long term seepages, and leaks from vessels can add to a synergistic mixture of threats whose exact effects are still largely unknown. It is clear however, that a decision to reject offshore oil is a precautionary measure that will go a long way towards protecting Belize's dolphins.

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THE FATE OF MANATEES IN BELIZE[1]

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ABSTRACT

Sirenians (manatees and dugongs) are the only fully aquatic, herbivorous marine mammals existing today and Belize boasts the largest number of Antillean manatees in the world. Yet, the country's manatee population is considered threatened and may be declining. Manatees have to contend with high-speed watercraft that account for over 20% of their mortality. Also, intentional habitat alteration and industrial practices fragment and destroy the ecosystem they depend upon. Land-based effluent has decimated sub-aquatic vegetation and has likely compromised individual manatee health in areas such as Placencia Lagoon. High levels of toxic trace elements, including lead, were also found in manatees captured there. With limited data on the threats of contaminants to manatees, a pilot study showed that organic contaminants (polychlorinated biphenyls - PCBs) in manatees from Chetumal Bay may currently present a threat to their immune function and reproduction. Marine currents may allow PCBs to be present at a regional level. Also, as radio-tracked manatees have been documented to travel between Belize and Chetumal Bay, they are further exposed to organic compounds through inadvertent consumption of sediment during grazing. Added petrochemicals would further contaminate and destroy manatee feeding areas as the toxic components of oil are thought to accumulate in seagrass leaves, making vegetation vulnerable to these stressors. After an oil spill, manatees, dolphins and turtles are exposed to volatile hydrocarbons while traveling and feeding, as shown from surveys following the 2010 BP Deepwater Horizon catastrophe in the Gulf of Mexico. While experiments on captive marine mammals indicate that manatees can withstand small amounts of exposure to, or ingestion of, oil, it is not certain if these animals can detect, avoid, or leave a contaminated area before experiencing significant harmful effects. With very limited data on the effect of oil-related stressors to sirenians, we know that the threats they face today, compounded with the incalculable environmental damage of an oil-related disaster, would certainly affect the chances for survival of the endangered manatees in Belize.

INTRODUCTION

Three species of manatees are included within the Mammalian Order Sirenia: the Amazonian manatee (*Trichechus inunguis*), the West African manatee (*T. senegalensis*), and the West Indian manatee (*T. manatus*). Dugongs (*Dugong dugon*) are also in this Order, and live exclusively in the Pacific Ocean. The West Indian manatee is divided into two subspecies: Florida (*T. manatus latirostris*) and Antillean (*T. m. manatus*). This species inhabits fresh, brackish and marine waters in the Wider Caribbean, from Florida to the northeastern coast of South America. They need access to freshwater, and thus remain in relatively shallow coastal waters (within 3 m depth; Hartman, 1979). They are the only fully aquatic extant herbivorous marine mammal. With a low reproductive rate and historically hunted throughout its range, manatees are considered vulnerable to extinction by the IUCN (Thornback and Jenkins 1982). Given the small population size and past exploitation, today Belize's manatee population has a low genetic diversity (low levels of haplotype diversity, microsatellite heterozygosity and allelic variation), as compared with other marine mammals, and endangered or bottlenecked populations (Hunter *et al.*, 2010).

Belize harbors the highest known density of Antillean manatees in the Caribbean (O'Shea and Salisbury, 1991; Auil, 1998). Status surveys were first conducted 32 years ago by Charnock-Wilson (1968) and Charnock-Wilson, Bertram and Bertram (1974), and later by Bengtson and Magor (1979) and O'Shea and Salisbury (1991). Further countrywide surveys have shown that while manatees are present along most of Belize's coastline from the Rio Hondo to Sarstoon, areas of consistently high presence include the

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Southern Lagoon, the Belize River and Belize City Caye area, Placencia Lagoon, Port Honduras, Corozal Bay, and Indian Hill Lagoon (O'Shea and Salisbury, 1991; Gibson, 1995; Auil, 1998; Morales-Vela *et al.*, 2000). Additionally, while there are higher numbers of manatees in the larger caye and coast habitats, the lagoon and river systems have a higher probability of manatee occurrences (Auil, 2004). The highest count during a survey was 338 manatees, so today, population estimates are approximated at about 1000 manatees in Belizean waters (O'Shea and Salisbury, 1991; Auil, 1998; Auil, 2004).

Although a developing country with limited available resources, Belize has proven to be a successful manatee conservation site. A rapidly growing and lucrative ecotourism industry is attractive to economically depressed communities, offering excellent prospects for touristic development that values wildlife and their habitats. There are several communities along the coast of Belize with facilities or activities for receiving visitors, and the clear coastal waters provide good conditions for viewing manatees for both scientific study and tourism. Fortunately, the country has taken the lead in manatee conservation and coastal conservation efforts in Central America, where Belize's efforts provide a model that can be used by other countries. Belize has an interagency management working group (Belize Manatee Working Group) that comprises government representatives, NGOs and scientists that carry out research and conservation initiatives throughout the country. Additionally, there are three sites declared as wildlife sanctuaries specifically for manatees: Corozal Bay, Swallow Cay, and Southern Lagoon.

Unfortunately, very little data exists on chemical contaminants on manatees, including heavy metals, trace elements and organic compounds. Virtually no data exists on the effect of oil on these coastal marine mammals. When indentified in samples, the biological response of an individual manatee to a contaminant is not always determined and cumulative response to toxins is unknown. In this report, I outline some research to describe our current knowledge of threats faced by manatees in Belize.

THREATS

Consistent assessment of manatee status began in August 1996 under the Coastal Zone Management Project at the commencement of the National Manatee Project. Threats to manatees, particularly in Belize, are predominantly anthropogenic. From January 2005 to December 2010, 76 reports of manatee strandings were received (Figure 1; Galves, 2011). Twenty-nine percent of these were unverified. For the carcasses that were located, examiners could not determine the cause of death for 38%, primarily as 43% of this 'undetermined' category was in an advance stage of decomposition or was not recorded. The number of strandings per year ranged from six in 2008 to 18 in 2010. There has been a recent increase in the number of strandings over the years that have researchers concerned. Watercraft collision has been the primary cause of identified death for each year (range 14% - 27%).

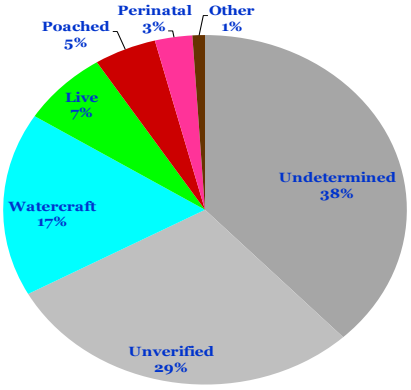

Figure 1. Cause of manatee strandings 2005 - 2010.

Habitat alteration

While we are unable to directly quantify manatee loss based on habitat destruction, we know that a reduction of the quality or quantity of the submerged, natant or overhanging vegetation they rely upon impacts manatee health. This is particularly so as their habitat, primarily seagrass beds, become fragmented. The health of seagrass meadows in shallow aquatic ecosystems varies with sediment and nutrient loading. Excessive nutrient loading can smother seagrass by stimulating the production of algae that block out light. Sediment re-suspension due to wind, riverine transport or boat traffic can also lower water clarity and produce the same result. Human activities that accelerate contaminant loading or over-exploit sensitive species can seriously impair and threaten these ecosystem services. These changes may persist long after disturbances have ceased, rendering habitats unsuitable. One case of significant sub-aquatic vegetation loss in a primary manatee habitat is in Placencia Lagoon, where formerly viable seagrass meadows have deteriorated rapidly due to contaminated run-off.

The seagrass *Halophila baillonii* provided the preferred forage for manatees in Placencia Lagoon (Short *et al.*, 2006; Auil Gomez, personal observation). A baseline study revealed that many areas in the lagoon retained critical ecosystem functions, populations of ecologically unique species, and seagrasses, and had little effluent influence prior to 2003 (Smith and Mackie, 2005). Recent data indicate those seagrass meadows were lost in the three years following, coinciding with aquaculture effluent (Gallego, 2004; Ledwin, 2010). The far northern basin of the lagoon has demonstrated low water clarity and sparse populations of submersed aquatic plants since sampling began in 2003 (Smith and Mackie, 2005). In 2006, in preparation for the first manatee capture event, the predominant vegetation recorded in the northern to central part of the lagoon was *Halophila*, along with some patches of *Halodule* and *Chara*. The leaves of the vegetation in the northern part of the lagoon were covered with strands of filamentous green algae, likely an effect of over-enrichment nutrient loading from shrimp farm and community septic systems (Auil *et al.*, 2007). The lagoon today has low water clarity and sparse submersed aquatic vegetation, with approximately 7% vegetation coverage within the system, compared with 83% reported back in 2003 (Ledwin, 2010).

Parasites

In 2007, an adult captive manatee from the Corozal Bay died of what appeared to be a verminous pneumonia during medical treatment. That case was very similar to a couple of cases reported by researchers in the southeastern US. In one of those cases a verminous pneumonia involving the fluke (*Pulmonicola cochleotrema*, formally referred to as *Cochleotrema cochleotrema*) was suspected as the proximate cause of death in an adult wild manatee from Georgia in the 1980s where a total count of 490 flukes resulted in interstitial pneumonia (Buergelt *et al.*, 1984). In another case over 250 flukes in the manatee's respiratory system resulted in severe rhinitis and pulmonary edema. Occlusion of the airways by *Pulmonicola*, especially if the animal is manipulated, could cause airway blockage and result in asphyxiation. Generally, with *Pulmonicola* infections there are only a few parasites present in the airways, but due to some underlying factors contributing to accelerated growth in the local manatee population, this condition could lead to vulnerability in the population and even death. It is suspected that another such case was encountered in a manatee captured in Placencia Lagoon in April 2007 (Auil *et al.*, 2007). Other manatees during that capture experienced mucoid discharge from the nasal passages that could have been due to the presence of an irritating parasite. More detailed studies are necessary in order to determine the etiology and significance of this debilitating parasitic condition in manatees in Belize. We hypothesize that effluent from shrimp farms has contributed to a bloom in algae providing food for a small snail which is likely the intermediate host of this parasite. These snails in turn attach to the vegetation consumed by the manatees.

Contaminants

Trace elements are introduced into coastal systems by industrial activities, including agriculture runoff, and they can reach potentially toxic levels. While many are essential to biological function, some, such as lead, are not. Trace elements can be directly and indirectly harmful to specific organs, or cause immune, neurological, or reproductive problems (Ramey, 2010). As manatees use nearshore habitats, in particular mangrove areas for grazing, they are at great risk as the substrate has a greater load of trace metals than other shoreline sediments (Ramey, 2010).

Tonya Ramey analyzed red blood cell samples of 95 manatees captured between 1998 and 2009 to establish a baseline for Belize of eleven trace elements (silver, arsenic, cadmium, cobalt, chromium, copper, iron, nickel, selenium, lead and zinc). There were measureable levels of each trace element in the manatee population, except for cadmium, which was found in only one individual (Ramey, 2010). While some manatees had high concentrations of certain trace elements, they were not thought to be at toxic levels (Ramey, 2010). The author determined that while the sex of the manatee did not have a significant effect on mean trace element level, age did, as younger (juvenile) manatees exhibited significantly higher concentrations of copper. Season and location also affected trace element concentration; for example, lead concentrations were higher in wet season than dry and were higher in the Southern Lagoon manatees than the Drowned Caye animals. One case of interest was a juvenile male caught in Placencia Lagoon that had 10 times the colbalt concentration and three times the lead and zinc concentration than the population average (Ramey, 2010). It is surmised that this animal could have such high concentrations due to foraging in areas of high agricultural contamination risk; and while it cannot be confirmed, immunosuppression may have occurred. These factors could certainly reduce not only the fitness of individuals, but the population on a whole.

It is assumed that because manatees are near the bottom of the food chain, they are not likely to bioaccumulate organic contaminants. A study by Mote Marine Lab and ECOSUR was carried out in the Chetumal Bay, Mexico, and in Florida, USA to examine a variety of organic compounds such as oil-related toxicants called polycyclic aromatic hydrocarbons (PAHs) and other persistent organic pollutants (POPs) including organochlorine pesticides (OCPs), brominated flame retardants (polybrominated diphenyl ethers—PBDEs) and polychlorinated biphenyls (PCBs). PAHs, which attach to suspended particles then settle into the sediment, were undetectable in both sample sets (Wetzel *et al.*, 2008); PAHs are mutagenic and carcinogenic. Additionally, the exposure subsequent to the spilled oil in Charlotte Harbor following Hurricane Charley did not appear to be a problem (Wetzel *et al.*, 2008). POPs were higher in Mexican samples than the Florida samples, but this was not significant; PCBs and OCPs affect the immune system and reproductive success (Wetzel *et al.*, 2008). While Chetumal Bay and the corresponding Belize portion of Corozal Bay constitute good manatee habitat, the land-based pollution is a concern and the area is considered high risk (Wetzel *et al.*, 2008). The PCB levels in Chetumal Bay in particular were high and are of concern; although the threshold for manatees is unknown, it could be affecting reproduction and immune function. Additionally, the contaminant levels in the environment are a concern as PCBs in sediments and seagrasses exceed sediment values alone (Wetzel *et al.*, 2008).

As marine currents likely carry these PCBs into Belize's waters, and manatee tracking data confirm movement of Belize's manatees to Chetumal waters (Auil *et al.*, 2007), it is very likely that the contamination exposure in the north of the country affect manatees that may be coming from the central or southern parts of the country. Examining the complex nature of a manatee's surroundings, we see that even if there are areas of available vegetation, manatees are susceptible to encounter toxins that they cannot detect or likely avoid in order to survive. Pockets of habitat have been negatively impacted, and when looked at cumulatively, the risk is high; therefore informed consideration needs to be given when dredging, clearing or filling projects are proposed. Manatee samples should be routinely processed to detect contaminants. Organic compounds, as well as trace elements in substrate and aquatic vegetation should also be examined in Belize to better understand what the manatees truly face.

Case Study: Deepwater Horizon Oil Spill

Approximately 185 million gallons of oil was released into the Gulf of Mexico after the Deepwater Horizon oil rig exploded on April 20, 2010, impacting five states in the US. The Gulf is not only an area for several fisheries, but is also used by threatened megafauna such as turtles, dolphins and manatees. As a response to the spill a study was initiated to determine the estimated abundance and distribution of manatees within and adjacent to the spill site, and to document locations of fouled areas or animals. A reconnaissance aerial survey was carried out prior to the spill and aerial surveys were carried out weekly from June 2010 to November 2010 (n = 76). A total of 21 manatees, 1,409 dolphins (97% *Tursiops truncatus*) and 9 turtles (*Caretta caretta*) was identified; visible oil was seen during 13 surveys (Ross *et al.*, 2011). Peak manatee sightings (July) were made after oil observations, but some occurrences overlapped with manatee sightings, however, none were observed in actively oiled surface waters (Ross *et al.*, 2011). The team determined that the distribution of manatees and other species was within the oiled region, including feeding areas, an area of approximately 7.4 km^2 of patchy seagrass habitat along the survey route (Ross *et al.*, 2011). Additionally, while manatee carcasses were examined after the spill, none in the Gulf of Mexico were determined to have had petrochemical contamination (A. Aven and A. Garrett, personal communication).

Conclusions

Marine mammals are exposed to a wide range of toxins in the oceans and coasts where they feed, breed and travel. It is unclear in most species how chemicals are absorbed, distributed, metabolized and excreted and what are their effects (O'Hara and O'Shea, 2001). As manatees are the primary consumers of vegetation in the marine mammal world, they would show rather different effects from exposure than most other marine mammals that are carnivorous. Oil, with its varied compositions (crude to mixtures of compounds), can come in direct contact with a manatee's external membranes or orifices including eyes, or can be inhaled, and ingested. While it is likely that they can withstand some level of ingested oil by metabolizing and removing it, as demonstrated in captive experiments (O'Hara and O'Shea, 2001), it is not clear how this would translate to wild animals in a complex system. Furthermore, it is not known if

individuals would be able to remove themselves from a contaminated area after receiving an exposure level that could be fatal.

The manatees' food base is certainly vulnerable to the effects of oil by direct mortality, reducing their ability to withstand additional stress, reducing flowering and leaf chlorophyll content, and oil penetration into sediment preventing new shoot growth. Given the complex nature of the aquatic system, especially within the coastal zone which is heavily impacted by land based activities, manatees would have another obstacle to contend with for survival if the petrochemical industry takes root in Belize's waters.

In contrast, if added protection and management are afforded the species and the coastal habitat, it would benefit not only the status of manatees in Belize, but neighboring countries as well, since Belize is thought to be a manatee source population for Central America.

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STATUS AND DISTRIBUTION OF SEABIRDS IN BELIZE: THREATS AND CONSERVATION OPPORTUNITIES[1]

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ABSTRACT

The Belize cays and atolls offer a wealth of opportunities for seabirds. Indeed, seabird breeding colonies once proliferated off the coast of Belize. These colonies have been under near constant threat from a variety of sources as far back as the mid-Nineteenth Century, and some have long since vanished. But, how many remain? Where are they located? What are the current threats to their survival? Can some of the extirpated colonies be re-established on cays that are now protected? The answers to these questions are largely unknown. Before the nature and severity of continuing threats and potential future threats, such as those emanating from oil development and transport in Belize, can be adequately assessed, a comprehensive baseline inventory of existing colonies must be established. Only then can we determine the most appropriate measures necessary to preserve and expand these colonies and perhaps to re-establish some of the colonies that have been lost over the years. Does oil development loom as the next significant threat to what remains of the seabird populations in Belize? If so, what measures can be taken to minimize or compensate for this threat?

INTRODUCTION

Seabirds play an important role in maintaining a healthy marine ecosystem. Most of the seabird species in Belize prey on small to medium-sized fish, and to a lesser extent on arthropods, mollusks, and other invertebrates. As important components of the marine ecosystem, seabirds are efficient tools for monitoring ocean conditions and, at least in some cases, as predictors of stocks of important fisheries (Cairns, 1992; Roth *et al.*, 2007). Because seabirds congregate in large flocks around schools of fish, they have been revealing optimal fishing locales ever since man took to the sea in his quest for food (Au and Pitman 1986, Erdman 1967, Johannes 1981). Additionally, tropical seabirds, especially those that nest in mangroves, enrich shallow-water fish nurseries with their nitrogen-rich excrement, or guano. Although it may seem counterintuitive, seabirds cull smaller and younger fish from schools, thereby reducing competition for food and allowing more fish to attain larger size–a benefit to sport fisheries that many modern-day fishers fail to recognize.

The collapse of seabird colonies around the world has had many causes, typically working in synergy. And while diminished seabird populations have frequently been concomitant with diminished or failed fisheries, it is often difficult to pin fisheries collapses directly on the collapse in seabird populations. Overfishing often goes hand in hand with over-harvesting of seabirds or their eggs, habitat conversion, and introduction of non-native predators as human populations expand beyond the capacity of the local resources to support them. For example, Christmas Island, part of the Republic of Kiribati in the western Pacific Ocean, had one of the largest seabird colonies in the world, with several million sooty terns and tens of thousands of 17 other species (Jones, 2000). Now, the numbers of seabirds there have been reduced by more than 90 percent, the result of rat infestations in their nesting colonies, poaching of their eggs for food, and in some cases the massacre of birds for both food and sport (Jones, 2000). At the same

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time, the human population of Christmas Island expanded from a few hundred people in the mid-20th Century to more than 5,000 people at the beginning of the 21st Century. Christmas Island's fisheries industry is now on the verge of collapse, but for reasons that that are only partially related to the collapse of its seabird colonies. With increasing pressure on fish populations from overfishing and the introduction of dynamite, cyanide, and modern longline and gillnet fishing techniques, the latter of which have been stretched across narrow openings in the lagoon to catch bonefish as they head out to sea to spawn, the rapid demise of the industry was a foregone conclusion.

This scenario in Belize, while not as severe, has several parallels. Belize's human population has nearly doubled in the past three decades. Rats have been inadvertently introduced to nesting islands. Seabird eggs have been collected for food. Fish populations upon which the seabirds, as well as humans, depend have been decimated by insufficient or inadequately enforced regulations, especially with respect to the inappropriate use of gill nets and a steep increase in the number of commercial boats, both domestic and foreign, fishing Belize's waters. The result: fish populations in Belize are in serious decline and no longer sustainable at present levels of harvesting (see also Zeller *et al*., this volume). While the general decline in fish populations has certainly had its impact on seabirds, the main direct cause of seabird declines in Belize has been the conversion of habitat for resorts, private residences, and seasonal fishing camps and the associated impacts caused by dogs, cats, and rats. Habitat conversion primarily involves mangrove cutting, removal of littoral forest and dredging of the seabed.

These problems are ongoing. They have not been resolved. With new threats on the horizon, including the cumulative effects of climate change and, possibly, contamination of the marine ecosystem from offshore oil extraction and transport, seabirds in the waters off Belize could soon be a thing of the past–unless the ongoing threats are diminished and the potential new threats are addressed proactively.

Materials and Methods

For the purposes of this paper, a seabird is any bird that nests on marine islands and forages in the marine environment. In Belize, that includes members of the Fregatidae, Sulidae, Phalacrocoracidae, Pelecanidae, Ardeidae, Threskiornithidae, Pandionidae, and Laridae. This paper provides a literature review of the past and current status of seabirds in Belize, along with an analysis of past, present, and perceived future threats to their continued presence in Belize. It also includes management and recovery recommendations designed to assure their survival, and in some cases, the re-establishment of populations that have been extirpated.

Results and Discussion

Credible information on seabird populations in Belize is sparse. Other than a few key publications that include brief synopses of seabirds (Oates, 1901; Russell, 1964; Jones, 2003) or largely anecdotal accounts (Salvin, 1864; Sclater and Salvin, 1869), most available information comes from the field notes and verbal accounts of biologists who have visited the cays, often only briefly. The one exception is Jared Verner's Master's thesis (1959) and subsequent publication (Verner, 1961) on the Red-footed Booby (*Sula sula*) colony on Half Moon Caye. Gaps in our knowledge in some cases span several decades, thus making it all, but impossible to determine any meaningful population trends over time. Almost nothing in the literature, or otherwise, documents anthropogenic threats to seabirds or the consequences of these threats. In short, we know very little about the past or current status of seabirds in Belize. We know that a few species that once nested in Belize have been extirpated or nearly so. We also suspect that a few species now nest in Belize that did not occur historically. A summary of seabirds found historically in Belize is presented in an Appendix at the end of this contribution (see also Paleczny, this volume).

Past and current status

The first records of seabirds in Belize come from Osbert Salvin (1864) who spent two weeks in May 1862 on several of the Belize cays collecting seabirds and their eggs. We have very little information on Belize seabirds after 1862, until nearly a hundred years later when two ornithologists from Louisiana State University independently visited Belize: Jared Verner, whose studies pertained specifically to one species, the Red-footed Booby, and Stephen M. Russell who, from 1955 to 1961, conducted an inventory and literature review of all birds then known to occur in Belize (Russell, 1964). The Belize Audubon Society sponsored field trips to several of the cays, primarily in the 1980s and early 1990s, led mostly by W. Ford Young, Dora Weyer, Meg Craig, and Martin Meadows. Meadows and Lee Jones (unpublished notes)

visited most of the southern cays in late May 1998. Luz Hunter, Philip Balderamos, Erneldo Bustamante, and Tony Rath documented a significant mixed-species tern colony on Tobacco Caye in July 2002, but it has since vanished. In late February and early March 2007, Betty Ann Schreiber (unpublished notes) and Robert Fleischer visited many cays where seabirds were known to have nested in the past, but their visit was too early in the season to capture the breeding season of terns and a few other species. Thus, to date, the only efforts that even approach a comprehensive inventory of Belize seabirds was Salvin's two-week visit to the northern cays in 1862 and Jones' and Meadows' brief visit to the southern cays in 1998.

Salvin was the first to characterize the Red-footed Booby colony on Half Moon Caye, Magnificent Frigatebird (*Fregata magnificens*) colonies on Half Moon Caye and Man-O'-War Caye, and significant colonies of Brown Noddy (*Anous stolidus*) and Black Noddy (*Anous minutus*) at Glovers Reef. He found Double-crested Cormorants (*Phalacrocorax auritus*), but not Brown Pelicans (*Pelecanus occidentalis*) nesting on Man-O'-War Caye; whereas, when visited 94 years later Russell found the latter nesting, but not the former. Salvin also found Snowy Egrets (*Egretta thula*) nesting there, but no nesting of this species in Belize has been documented since. Small colonies of cormorants and pelicans have recently been found on several other cays.

Salvin estimated the presence of several thousand Red-footed Boobies on Half Moon Caye. The colony was already well known to Belizeans at that time, but the literature contains no specific references to this colony prior to the publication of Salvin's 1862 expedition in 1864. When next reported in the literature 96 years later, Verner (1959) counted 1,389 nests, but did not estimate total number of birds present. Belize Audubon Society (1992) similarly estimated 1,325 nests in late 1991. In 2007, however, Schreiber counted only 157 occupied nests, a number that is consistent with Jones' impressions from visits to the cay in 1999, 2004, and 2010. While numbers of Red-footed Boobies at Half Moon Caye appear to have decreased dramatically in the last two decades, Magnificent Frigatebird numbers appear to have remained relatively constant at around 60 to 80 pairs, although precise numbers are not available for any period. The same appears to be true for frigatebirds on Man-O'-War Caye, where reported numbers have ranged from 60 to 100–110 occupied nests.

Although apparently known for a number of years previously, in early 1984 the Belize Audubon Society reported on a small Tricolored Heron (*Egretta tricolor*) and Reddish Egret (*Egretta rufescens*) colony on two small mangrove cays, Little Guana Caye and Cayo Pajaros, on the Chetumal Bay side of Ambergris Caye (Belize Audubon Society, 1984a). That year, Belize Audubon Society (1984a) also documented Great Egret (*Ardea alba*) nesting well to the south on Little Monkey Caye near the mouth of Monkey River. In 1990 and 1994, Meadows (Belize Audubon Society, 1991; and unpublished notes) found Tricolored and Reddish egrets, as well as Double-crested Cormorants, Great Blue Herons (*Ardea herodias*), and Roseate Spoonbills (*Platalea ajaja*) nesting on Cayo Rosario not far from Little Guana Caye and Cayo Pajaros, and found White Ibises (*Eudocimus albus*) nesting there in 1994. Estimates of the number of breeding birds or nests were not given in these brief accounts.

Several species of terns have been found nesting from time to time on various cays. In 1862, Salvin found "many thousands" of Brown Noddies nesting at Southwest Caye on Glovers Reef and others nesting at Ellen (now known as Carrie Bow), Curlew, and South Water cayes. Although not recorded on later surveys at these three cays, they persisted on Southwest Caye in numbers exceeding 100 pairs at least through 1956 (Russell, 1964), and five birds (nesting status not mentioned) were seen there as late as 1986 (Triggs, unpublished notes). It apparently has not nested there in recent decades, and a resort now occupies most of the cay. Nearby Middle Caye was restored in the 1990s by the Wildlife Conservation Society and is uninhabited except for research facilities and a small staff at the north end, but no noddies or other seabirds currently nest there. In 2002, ten adults on Tobacco Caye were behaving as if they were nesting, but no direct nesting evidence was obtained. There are no other recent records of Brown Noddy nesting in Belize.

In addition to Brown Noddy, Salvin also found Black Noddy nesting on Southwest Caye in 1862 (Table 1), but he gave no estimate of its numbers. Berry (cited in Russell, 1964) also found it there and on Morgan Caye (now known as Northeast Caye, also at Glovers Reef) in 1907. We have not been able to find any definitive records of Black Noddy nesting in Belize since 1907; in fact, there are only a handful of credible reports of the species at all in Belize since then. Two other congeners, Sooty Tern (*Onychoprion fuscatus*) and Bridled Tern (*Onychoprion anaethetus*), have also nested in Belize. Salvin (1866) "only met with a few solitary" Sooty Terns in 1862, and it was not found nesting in Belize until 1958 when Verner (cited in

Russell, 1964) found a colony with nests containing eggs on Round Caye. In 1971, Henry Pelzel (unpublished ms) had 200-400 pairs on the Silk Cayes. Sometime later, a colony of similar size was discovered on Middle Snake Caye (first mentioned in the literature in 1990; Belize Audubon Society, 1991), but there have been no more confirmed reports from the Silk Cayes. The colony on Middle Snake Caye persisted until around 2008, but was recently abandoned. It is reported to now be on Tom Owens Caye, but this has not been confirmed.

Table 1. Nesting history of Brown and Black noddies in Belize.

Cay	1861–1910	1911–1960	1961–2010
Morgan (=Northeast)	Black nested in considerable numbers (Salvin, 1864)	–	–
Southwest	1,000s of Brown, unknown number of Black	Brown nested in the hundreds	5 Brown "present" in 1986
Ellen (=Carrie Bow)	A few Brown nested	–	–
Curlew	A few Brown nested	–	–
Pompion	Not visited	Brown nested	
Tom Owens	Black may have nested	–	–
Tobacco	–	–	10 Brown behaving as if nesting in 2002

Salvin found nesting colonies of Bridled Tern on Saddle, Ellen, and Curlew cays, and possibly South Water Cay in 1862 (Salvin, 1864; Russell, 1964), but it was not reported again from Belize until April 1994 when Meadows (personal communication) observed six pairs attempting to nest on a small artificial cay between Caye Caulker and Ambergris Caye. Four years later, Jones (unpublished notes) and Meadows found a few pairs nesting on several cays along the reef off southern Belize. Lastly, 12 adults were observed by Luz Hunter and her colleagues behaving as if they had nests on Tobacco Caye in July 2002 (Jones, 2002).

Laughing Gull (*Leucophaeus atricilla*) and Sandwich Tern (*Thalasseus sandvicensis*) are both common along the coast and cays of Belize, but there are few confirmed records of either species breeding in the country. Although Laughing Gull was rumored to nest in Belize for many years, no direct evidence was obtained until May 1998 when Jones (unpublished notes) and Meadows found about 20 nests with eggs on Lawrence Rock at Seal Caye and one nest with eggs on Black Rock. Although never documented, Laughing Gulls almost certainly nested on Laughing Bird Caye before the island was decimated by Hurricane Greta in 1978 and ultimately driven away, presumably by egg collectors, fishers, and tourists, about ten years later (Malcolm Young, personal communication to Lee Jones). It has not nested there since the island, associated reefs, and surrounding waters were designated a national park in 1991.

Although Sandwich Tern eggs were collected by Salvin on Northern Two Cayes presumably in 1862 (Oates, 1901), the species was not recorded in Belize again until the early 1960s when a few were seen in Chetumal Bay and Belize Harbor (Russell, 1964). The species has increased dramatically in number since then, but primarily as a non-breeding visitor. Jones and Meadows found about 100 pairs nesting in a dense colony on a small sandbar near North Spot (coordinates 16°15' N, 88°12' W) in 1998. The only other record of nesting in Belize comes from Tobacco Caye where Luz Hunter and her colleagues found 50 birds with large chicks and fledglings in July 2002 (Jones, 2002).

Roseate Tern (*Sterna dougallii*) has also nested in Belize, although little information on this species is available. In 1862, Salvin collected a male from three to four birds present on Grassy Caye where he thought they were "preparing to breed". Luz Hunter and her colleagues counted roughly 200 chicks on Tobacco Caye 140 years later (Jones, 2002), and L. Cottle (*fide* Betty Ann Schreiber) found Roseate Terns breeding at two sites on the Grassy Caye Range in June 2006. They do not currently breed on Tobacco Caye as confirmed by Philip Balderamos, and their current status on the Grassy Cayes is not known. Roseate Tern is a threatened species in the Caribbean (USFWS, 1987). Belize could play a significant role in its recovery based on the fact that it is occasionally seen in Belizean waters in numbers that exceed 100 birds, has bred as recently as 2006, and may currently be breeding, but undetected.

Although seldom documented, Least Tern (*Sternula antillarum*) is known to nest at various locations along the mainland coast, as well as on a few cays. Salvin found a few pairs ready to lay on Long Caye and "above a hundred pairs" nesting on Grassy Caye in 1862 (Salvin, 1864). According to Belize Audubon Society (1984b), it nests (or nested) on one of the Drowned Cayes near Gallows Pt. Reef 11-12 miles (18-19 kilometers) east of Belize City. Meadows (unpublished notes) found 70 birds and 12 nests with eggs and

chicks in Bella Vista outside Belize City in May 1988 where they are now reported to nest annually. He also found about ten grown juveniles on a small sandbar near Cayo Rosario in July 1994. Hunter *et al*. found 20 large chicks on Tobacco Caye in July 2002 (Jones, 2002). Schreiber (unpublished notes) reported that L. Cottle found Least Terns nesting at two sites on the Grassy Caye Range in June 2006, and Jim and Dorothy Beveridge (personal communication) believe that it nests each summer north of the airstrip on the lagoon side of Caye Caulker, although they have not been able to access the site and have not observed eggs or chicks.

According to the definition used in this paper, Ospreys of the subspecies *Pandion haliaetus ridgwayi* that is endemic to the Caribbean are seabirds. In Belize and elsewhere in the Caribbean, they nest exclusively on cays and feed on fish that they catch in nearshore waters. These Ospreys have shown a remarkable ability to adapt to human activities, and one or more pairs nest on most of the cayes, even those that have long been inhabited. We could find no evidence that numbers of this species have declined in Belize, although, as with other seabird species in Belize, specific nesting information is scant and no definitive conclusions can be drawn.

Historical and ongoing impacts

Anthropogenic impacts on seabirds in Belize have included deliberate intervention in the form of egg collecting, shooting, and vandalism, along with unintentional impacts resulting from tourists, fishers, and others repeatedly entering breeding colonies and causing abandonment. Less direct, but equally destructive, and often much longer lasting impacts have included dredge-and-fill operations, along with replacement of mangroves and littoral forest, for coconut plantations, fishing camps, private homes, and resorts. An inevitable result of repeated human visitation and habitation has been the introduction of non-native predators such as cats, dogs, and rats.

While there is no evidence that the limited amount of specimen and egg collecting in the past has resulted in colony failure, persistent shooting, vandalism, and egg harvesting by local fishers, recreational boaters, and others have certainly played a major role in the demise of seabird colonies in Belize. Although potentially severe, these impacts usually do not result in permanent abandonment. Elimination of breeding habitat, on the other hand, does result in permanent loss of breeding colonies. An example of this may be Middle Caye on Glovers Reef. When Salvin visited Glovers Reef in 1862, he found terns nesting on all the cays except Middle Caye, which must have had nesting seabirds in the past, but was already inhabited by the mid-1800s. The native vegetation had been cleared to make way for a coconut plantation, undoubtedly the reason seabirds were no longer breeding there in the 1860s. Now, 150 years later, the coconut plantation is gone and the native vegetation has been restored. The island has a small marine station at its northern end and is fully protected. Yet, there are still no seabirds breeding on the island. Permanent developments and associated habitat conversion have replaced seabird colonies on the other three cays at Glovers Reef and at South Water Caye, Round Caye, Pompion Caye, and perhaps a few others where seabird colonies were never documented prior to their development.

Associated with human habitation on many islands are domestic dogs and cats and, unintentionally, rats of the genus *Rattus*. Introduced non-native species are a leading cause of extinctions in island communities (Atkinson, 1985). Rats, alone, are responsible for 40 to 60 percent of all recorded bird and reptile extinctions worldwide. Although rats have not been implicated in the loss of any seabird colonies in Belize, they have surely played a role, along with other, more direct, human intervention. Black Rats (*Rattus rattus*) are a suspected culprit in the decimation of the Red-footed Booby colony on Half Moon Caye. Although booby colonies worldwide have tended to survive rat infestations, rat depredation has been mentioned as a possible cause of depletion of all three booby species that occur in the Caribbean (Nelson, 1978; del Hoyo *et al*., 1992; Priddel *et al*., 2005).

Lastly, climate change is likely to have impacts of uncertain magnitude on seabird colonies in Belize and worldwide in coming decades. The warming of the oceans has already been demonstrated to have had a profound effect on both the intensity and frequency of tropical storms, including hurricanes, and prolonged droughts in many regions of the world. Recent studies have also demonstrated that the oceans have become more acidic as they absorb human-generated carbon dioxide from the atmosphere, and more oxygen-deprived as they absorb agricultural runoff, factors that in turn will further accelerate climate change (Rogers and Laffoley, 2011).

Potential impacts of oil extraction and transport

If we are to be in a position to assess the potential impacts from oil development on seabirds we need to first know what species still breed in Belize, where they breed, and how large their colonies are. This will require a comprehensive survey of all known sites, past and present, and perhaps other sites where seabirds may be breeding, but as yet undetected. We also must be able to document the nature and extent of existing threats and the degree to which these threats can be rectified or managed. Only then will we have the tools necessary to evaluate the nature and extent of future impacts and to devise effective measures to avoid, eliminate, reduce, or compensate for those impacts. More specifically, we need to determine what the threat of oil development is, relative to existing threats, and design management and conservation programs that place these ongoing and perceived future threats in perspective.

If oil development in Belize poses potentially catastrophic threats to the marine ecosystem in the Gulf of Honduras, as some have asserted, then every effort should be directed toward rethinking the extraction and transport process. The relative benefits and costs of oil development should be carefully weighed against the potential costs to Belize's precious marine resources and the economic and cultural benefits that derive from their protection. If, on the other hand, the amount of oil ultimately extracted from and transported through Belizean waters is relatively small and can be extracted and handled safely with proper precautionary measures in place and being enforced, then conservation efforts should perhaps be focused elsewhere where they can be of greater benefit.

Different groups of birds, depending on their specific foraging behavior, nesting substrates, and other factors, have differing degrees of vulnerability to oil contamination. Of the seabirds that breed or otherwise reside in Belize, Double-crested Cormorant, Brown Pelican, and Laughing Gull are most vulnerable to offshore oil contamination, as these species spend much of their time in the water. They are all locally abundant near the mainland coast and around the cays and essentially absent beyond the reef and atolls. Boobies spend less time on the water, and terns spend essentially no time on the water, but both groups feed by plunging into the water from the air. Boobies detect fish by sight and, as fish cannot be seen through oily waters, they generally avoid foraging in or landing on oil slicks (del Hoyo *et al.*, 1992).

Terns, like boobies, are plunge divers, but unlike boobies they do not rest on the water. Whether or not terns will forage in an oil slick is not known to us, but because most species nest on the ground often just above the high tide line, they could be vulnerable to contamination from oil that washes up on beaches, especially during spring tides. The most common tern species in Belize are the Sandwich Tern and Royal Tern, although only Sandwich has bred in Belize and documented instances are few. Both are common in nearshore waters, including near and at the cayes, where they would be most vulnerable. Least tern is seasonally common along the mainland coast from March to October and breeds (or has bred) locally on several cays. It does not typically venture far from shore, however, and would be most vulnerable to spills near land.

Several other species of terns breed or formerly bred on the outer cays, but most of these are now rare or absent or their current status is not known. Sooty Tern can be seasonally abundant near its breeding colonies, but its current status in Belize is unclear. Outside the breeding season (roughly September to March) it is found far offshore over deep waters in the Caribbean. Very little is known about the current breeding status of three other species: Brown Noddy, Bridled Tern, and Roseate Tern. Black Noddy is no longer part of the regularly occurring Belize avifauna.

It is unknown if the long gaps between breeding or suspected breeding of many of the terns in Belize are due to their absence or near absence in the western Caribbean during these periods or if they have simply been overlooked. With the paucity of visits to many of the small outer cays where most species are most likely to breed, the latter is certainly feasible. Because so little is known about these species, it would be impractical to assess their vulnerability to oil spills in Belize waters at this time. In the overall scheme of things, however, their vulnerability must be small because they are so rare and/or local in the country and only seasonally present, not year-round inhabitants.

Ospreys typically grab fish at the surface with their talons, but occasionally plunge into the water to catch their prey. Like terns, they do not rest on the water, and like boobies they are not likely to forage over oil slicks; thus, their vulnerability to oil contamination must be minimal.

Magnificent Frigatebirds generally are not susceptible to oiling, although they may ingest some oil with their prey. They do not land on the water and catch their prey either by pirating it from other birds in flight or picking it off the water's surface with their bill while in flight.

Herons, ibises, and spoonbills are long-legged wading birds that feed in shallow water. Only those species that nest in colonies on the cays are considered in this paper. Members of this group rarely if ever swim or float in water. They are most vulnerable to oil contamination along inshore waters where feeding groups congregate, and near their rookeries. While they are not as likely to have their plumage saturated with oil from direct contact, they are vulnerable to the toxic effects of ingesting oil that may be present in or on their prey. They may also transfer small amounts of oil from their beaks and feet to their feathers when preening or scratching.

Conserving what we have and restoring what we have lost

As discussed above, many of the cays that supported seabird colonies in the past are now developed and have few or no remaining seabirds. Others like Middle Caye (Glovers Reef), Laughing Bird Caye, and Middle Snake Caye are now ostensibly protected, but have no nesting seabirds, although Sooty Terns may return to the latter as they have in the past. Some, like Tom Owens Caye, are either developed or support fishing camps, but still have small numbers of breeding seabirds. For many others, we have no recent information or seabirds tend to nest on them only sporadically, perhaps due to periodic disturbance by fishers, tourists, and vandals. Very few cays with seabird colonies are both protected and patrolled regularly. Half Moon Caye may be the only example. But, being protected and patrolled is often insufficient. On Half Moon Caye, Black Rats are abundant. They readily climb trees and are well known predators on the eggs and young of unattended nests of many species, although little information has been published on their effect on boobies.

Regular patrols, coupled with increased enforcement of existing laws will, however, help in reducing poaching, vandalism, wanton habitat destruction, and unauthorized access to sensitive seabird areas. But, patrolling an area as vast as the Belize cays necessitates a considerable increase in personnel, patrol boats, equipment, and training and a considerable expenditure of money. Educational programs in the schools and community centers of Belize would also go a long way toward altering the mindset of those who may not otherwise appreciate the economic value and benefits that accrue from responsible management and conservation of Belize's seabirds and other natural resources. Such benefits include an increase in ecotourism, a cleaner, healthier marine environment, and improved commercial and recreational fisheries.

In the last few decades, rats have been successfully eradicated from several hundred islands around the globe (Taylor and Thomas, 1993; Howland *et al.*, 2007; Fischer and Dunlevy, 2010), including some much larger than Half Moon Caye. In case after case, seabirds that had been eradicated or nearly eradicated from these islands by rats (and sometimes cats) have returned and are now flourishing (Seniloli, 2008). The same could be accomplished on Half Moon Caye at modest expense.

Recent successes in attracting seabirds back to islands where they once bred have also met with success (Kress, 1983, 1998; Kress and Nettleship, 1988; Parker *et al.*, 2007). Typically, decoys and broadcast calls of the target species are set up on the desired island at the onset of the breeding season, and if birds are in the area, they may settle in and form the nucleus of a new colony. But, beforehand, all rats, cats, and other non-native predators must be removed if any new colony is to have a chance of succeeding. Middle Caye on Glovers Reef is ideally suited for this purpose. Suitable habitat for both Brown Noddy and Black Noddy is present, and they both formerly nested in large numbers at Glovers Reef. Economic incentives abound for re-establishing seabird colonies in Belize. Ecotourism is an obvious one. The oil industry can play an important role in assuring that these once flourishing colonies return. With the implementation of proven measures designed to prevent oil leakage and spills during the processes of extraction, handling, and transport, the threat of further damage to the already decimated seabird populations in Belize can be all but eliminated.

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APPENDIX: GAZETTEER OF HISTORICAL SEABIRD COLONY SITES IN BELIZE

Chetumal Bay

Shipstern Caye:	White Ibis
Cayo Rosario:	Double-crested Cormorant, Great Blue Heron, Tricolored Heron, Reddish Egret, Roseate Spoonbill, Least Tern (nearby) , Wood Stork(?), Brown Pelican(?)
Little Guana Caye:	Tricolored Heron, Reddish Egret, White Ibis
Cayo Pajaros:	Tricolored Heron, Reddish Egret, White Ibis
Unspecified cayes:	Wood Stork, Roseate Spoonbill, Bridled Tern(?)

Inner Cayes

Northern Inner Cayes	
Hick's Cayes:	Brown Pelican
Drowned Cayes	Least Tern
Southern Inner Cayes	
Laughing Bird Caye	Laughing Gull (never confirmed, but almost certainly nested there)
Little Monkey Caye	Great Egret
Middle Snake Caye	Sooty Tern, Bridled Tern(?)
East Snake Caye	Brown Pelican
Mangrove Cayes	Brown Pelican, Great Blue Heron
Outer Cayes	
Caye Caulker	Least Tern(?)
Sergeant's Caye	Brown Noddy specimen taken here
Man-O'-War Caye	Magnificent Frigatebird, Double-crested Cormorant (1862), Brown Pelican, Snowy Egret (?), Brown Booby allegedly
Tobacco Caye	Least Tern, Roseate Tern, Sandwich Tern, Brown Noddy(?), Bridled Tern(?)
South Water Caye	Brown Noddy, Bridled Tern (?)
Carrie Bow Caye	Brown Noddy, Bridled Tern
Curlew Caye	Brown Noddy, Bridled Tern
Tarpum Caye	Important roosts of Magnificent Frigatebird and Brown Pelican
Silk Cayes	Sooty Tern
Round Caye	Brown Noddy, Sooty Tern, Bridled Tern
Pompion Caye	Brown Noddy; Bridled Tern
North Spot	Sandwich Tern
Red Rock and Black Rock	Laughing Gull, Bridled Tern
Tom Owen's Caye	Bridled Tern, Sooty Tern(?), Black Noddy(?)
Lawrence Rock	Laughing Gull, Bridled Tern

Atolls

Lighthouse Reef	
Northern Two Cayes	Sandwich Tern
Saddle Caye	Bridled Tern
Half Moon Caye	Magnificent Frigatebird, Red-footed Booby
Turneffe Islands	
Mauger Caye	Brown Booby allegedly
Grassy Caye	Least Tern, Roseate Tern, Great Egret(?), White Ibis(?)
Unspecified caye	Great Blue Heron
Glovers Reef	
Northeast Caye	Black Noddy
Long Caye	Least Tern
Middle Caye	Apparently there are no historical records of seabirds breeding on this now protected and restored caye
Southwest Caye	Brown Noddy, Black Noddy

POTENTIAL THREATS OF MARINE OIL DRILLING FOR THE SEABIRDS OF BELIZE[1]

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ABSTRACT

In their 2011 report, the Belize Audubon Society conlcudes that seabirds are an important component of the marine ecosystem and internationally renowned ecotourism industry in Belize. This paper intends to inform decision makers about the potential threats that marine oil drilling could have on this important component. Included is a brief review of the literature on the interactions between seabirds and marine oil drilling and a summary of the status and distribution of seabirds of Belize. This is followed by an assessment of probability of negative impacts to seabirds caused by marine oil drilling in Belize, based on the knowledge and experience described in the literature. Results indicate that marine oil drilling would negatively impact the seabirds of Belize.

INTRODUCTION: INTERACTIONS BETWEEN SEABIRDS AND MARINE OIL DRILLING

Marine oil drilling affects seabirds in three key ways, as:

Attractants: Marine oil platforms attract seabirds because of increased prey concentration, roosting refuge and interest in lights and flares (Wiese *et al.*, 2001). Seabirds have been observed at concentrations up to 38 times higher surrounding marine oil platforms than in adjacent waters (Wiese *et al.*, 2001).

Obstacles: Marine oil platforms can be an obstacle to seabird flight, causing collisions either by accident during low-visibility conditions or because of attraction to lights and flares (Wiese *et al.*, 2001). These collisions cause episodic mortality that is poorly documented by independent scientists, but can cause mortality of up to tens of thousands of seabirds per collision event (Montevecchi, 2006).

Pollution: Marine oil platforms release oil into the water, via accidental spills and intentional discharge. Accidental spills from marine oil platforms can be very large (e.g., Ixtoc 476,000 tonnes, Nowruz 272,000 tonnes, Deepwater Horizon 700,000 tonnes), although intentional release during normal operation probably amounts to greater volume than accidental spills (GESAMP, 2007; US Gov, 2010). In total (i.e., accidental and intentional), an average of 16,400 tonnes of oil are reported spilled into the world's oceans from marine oil platforms every year (GESAMP, 2007).

Oil pollution can cause seabird mortality in two notable ways. First, oil in water can be ingested during feeding or preening, causing digestive and osmoregulatory disorders, reproductive failure, reduced immunity, and mutations in seabirds (Burger and Fry, 1993). Second, oil in water can foul seabird feathers, reducing insulation and buoyancy, which then causes hypothermia, exhaustion and starvation (O'Hara and Morandin, 2010). Throughout history, seabird die-offs have been documented after large oil spills. For example, the Exxon Valdez 1989 and Gulf of Mexico 2010 spills killed 250,000 and several thousand seabirds respectively (Piatt and Ford, 1996; Safina, 2011). It is important to note that seabird mortality caused by small oil spills is not typically reported, yet the cumulative impact on seabird populations may be greater than that of large spills (Wiese and Robertson, 2004). Recent research has revealed that even the smallest of oil spills, sheens invisible to the naked eye, can be lethal to seabirds (O'Hara and Morandin, 2010).

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STATUS AND DISTRIBUTION OF SEABIRDS IN BELIZE

A review of the status and distribution of seabirds in Belize is available in this volume (Jones and Balderamos, this volume). In general, breeding colonies are small and scattered, with the exception of two important sites, Half Moon Caye and Man-O-War Caye (Miller and Miller, 2006). Here I also present a map of all documented seabird colonies in Belize (Figure 1), which demonstrates widespread use of islands and cays; and a table describing the approximate abundance and habitat use for all species (Table 1), which concisely describes the seabird community of Belize and its use of both coastal and pelagic habitat. Several species have been affected by threats such as introduced predators, habitat destruction, poaching, persecution, pollution and unsustainable fishing (for more details, see: Jones and Balderamos, this volume; Miller and Miller, 2006).

Figure 1. Map of all documented seabird breeding sites (black dots) within Belize (Miller and Miller, 2006; Jones, 2003; Jones and Balderamos, this volume).

MARINE OIL DRILLING AND SEABIRDS OF BELIZE

Should Belize choose to go forward with marine oil drilling, the potential for marine oil platforms overlapping with seabird habitat is high, since seabirds are widely dispersed throughout islands, cays, and the pelagic environment. Furthermore, we can expect spatial overlap to be increased by seabird behaviour (i.e., concentrating around platforms). The probability of collisions between sea birds and oil platforms is also high, since seabird collisions have been documented in all marine oil drilling regions. The frequency and overall mortality caused by collisions is impossible to predict because of the abovementioned lack of independent research on this topic, particularly for the Belize seabird fauna. In the nearby Gulf of Mexico, collisions with marine oil platforms have been estimated to cause 200,000 deaths of migrating birds per year, an unspecified fraction of which are seabirds (Russell, 2005). The probability of pollution having negative effects on seabirds is also very high, given the guaranteed operational discharge plus the chance of accidental spills. Rate of mortality is impossible to predict, given the unpredictable nature of accidental spills and the lack of data on non-trivial seabird mortality caused by operational discharge.

Although it is impossible to predict the amount of mortality that will be caused by marine oil drilling, it is possible to predict based on experience that mortality will occur. Given that many seabird populations in Belize are small and/or already threatened, it is unlikely that they can withstand additional threats without facing population declines. Thus, it is very probable that this mortality will have population-level impacts.

CONCLUSIONS

Based on the status and distribution of seabirds in Belize, and the threats associated with marine oil drilling, it is apparent that marine oil drilling is an activity that will have negative effects on the seabirds of Belize. A precautionary approach of banning marine oil drilling would benefit seabirds and the related ecotourism economy.

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Table 1. Classification (Peters, 1979), habitat (Jones 2003; *Sea Around Us Project* Database, 2011) and abundance estimate (Miller and Miller, 2006; updated by Jones, *personal communication*) for all seabird species that occur (breeding and non-breeding; but not vagrant) in Belize.

Common name	**Order**	**Family**	**Genus**	**Species**	**Habitat (c=coastal, p=pelagic)**	**Abundance (# individuals)**
Black Noddy	Charadriiformes	Laridae	*Anous*	*minutus*	P	0-50
Black Tern	Charadriiformes	Laridae	*Chlidonias*	*niger*	C	500-1000
Bridled Tern	Charadriiformes	Laridae	*Sterna*	*anaethetus*	C	0-50
Brown Noddy	Charadriiformes	Laridae	*Anous*	*stolidus*	P	0-50
Common Tern	Charadriiformes	Laridae	*Sterna*	*hirundo*	C	50-100
Forster's Tern	Charadriiformes	Laridae	*Sterna*	*forsteri*	C	0-50
Herring Gull	Charadriiformes	Laridae	*Larus*	*argentatus*	C	50-100
Caspian Tern	Charadriiformes	Laridae	*Sterna*	*caspia*	C	50-100
Laughing Gull	Charadriiformes	Laridae	*Larus*	*atricilla*	CP	500-1000
Least Tern	Charadriiformes	Laridae	*Sterna*	*antillarum*	C	50-1000
Ring-billed Gull	Charadriiformes	Laridae	*Larus*	*delawarensis*	C	0-50
Roseate Tern	Charadriiformes	Laridae	*Sterna*	*dougallii*	CP	0-50
Royal Tern	Charadriiformes	Laridae	*Sterna*	*maxima*	C	500-1000
Sandwich Tern	Charadriiformes	Laridae	*Sterna*	*sandvicensis*	C	1000-5000
Sooty Tern	Charadriiformes	Laridae	*Sterna*	*fuscata*	P	1000-5000
Bonaparte's Gull	Charadriiformes	Laridae	*Larus*	*philadelphia*	C	0-50
Pomarine Jaeger	Charadriiformes	Stercorariidae	*Catharacta*	*pomarinus*	P	0-50
Magnificent Frigatebird	Pelecaniformes	Fregatidae	*Fregata*	*magnificens*	CP	1000-5000
Brown Pelican	Pelecaniformes	Pelecanidae	*Pelecanus*	*occidentalis*	CP	1000-5000
Double-crested Cormorant	Pelecaniformes	Phalacrocoracidae	*Hypoleucos*	*auritus*	C	500-1000
Brown Booby	Pelecaniformes	Sulidae	*Sula*	*leucogaster*	P	500-1000
Masked Booby	Pelecaniformes	Sulidae	*Sula*	*dactylatra*	P	0-50
Red-footed Booby	Pelecaniformes	Sulidae	*Sula*	*sula*	P	1000-5000
Audubon's Shearwater	Procellariiformes	Procellariidae	*Puffinus*	*lherminieri*	P	0-50

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THE ELASMOBRANCHS OF GLOVER'S REEF MARINE RESERVE AND OTHER SITES IN NORTHERN AND CENTRAL BELIZE[1]

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ABSTRACT

Glover's Reef Marine Reserve (GRMR) is one of the largest marine reserves in Belize. In 2000, our group initiated a study of the sharks and rays (elasmobranchs) at this site in order to (1) characterize local biodiversity, (2) determine the significance of GRMR as an elasmobranch nursery area and (3) broadly assess the potential of marine reserves for the conservation of sharks. Our surveys encompass the lagoon, the forereef and the deep benthic habitat (~400 m) off the edge of the reef slope. We documented the presence of at least 15 elasmobranch species at GRMR. Two species recorded in our survey, Galapagos sharks (*Carcharhinus galapagensis*) and night sharks (*Carcharhinus signatus*), had never been recorded in Belize before. We found evidence of local breeding in at least 7 elasmobranch species at GRMR and have maintained a standard time series of shark abundance since 2001. This survey indicates that the abundance of at least some species have remained stable at this site, suggesting that marine reserves can help protect certain shark species. Automated acoustic telemetry of Caribbean reef (*Carcharhinus perezi*, N = 34) and nurse sharks (*Ginglymostoma cirratum*, N = 25) showed that both species exhibit a high degree of fidelity to GRMR, which helps to explain the observed stable abundance trends. Since 2005, we have started surveying other areas in northern and central Belize, including Caye Caulker Marine Reserve (CCMR), Turneffe atoll (TU) and Southwater Caye (SW). Fished reefs (TU, SW) exhibit depressed populations of sharks relative to reserve reefs (GRMR, CCMR). However, both sites provide important nursery habitat for a variety of sharks, including scalloped and great hammerheads (*Sphyrna lewini*, *S. mokarran*), lemons (*Negaprion brevirostris*) and blacktips (*Carcharhinus limbatus*). Population genetic studies by us and others indicate that Mesoamerica harbors differentiated stocks of certain shark species that are not regularly replenished by immigration. Overall, we conclude that Belize has a diverse, largely self-sustaining elasmobranch fauna that is under serious threat from overexploitation and habitat loss.

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INTRODUCTION

Global exploitation of sharks is increasing and expanding, yet basic research and management continues to lag far behind (FAO, 2000). This trend is evident in the Belize, a country experiencing a level of population growth and increasing demand for its natural resources, which threatens the health of its marine ecosystems. Sharks and rays are some of the largest marine predators in Belize and some, such as the Caribbean reef shark, *Carcharhinus perezi*, southern stingray, *Dasyatis americana*, and nurse shark, *Ginglymostoma cirratum*, form the basis of a lucrative dive tourism industry. Indeed, a diver survey by the Coral Reef Alliance found that 'seeing sharks' was the primary attraction to Belize for the majority of respondents. Sharks are also fished for local consumption and for export, especially to the Asian dried fin market (Gibson *et al.*, 2005; Pikitch *et al.*, 2005). Beyond these direct commercial uses, sharks may perform critical ecosystem services that may even exceed their direct economic value (Heithaus *et al.*, 2008).

Directed shark fisheries have already drastically reduced shark populations in many parts of the world (Musick *et al.*, 2000). Sharks are extremely vulnerable to overexploitation because they exhibit a K-selected life-history strategy, reproducing more like mammals than teleost fishes (FAO, 2000; Musick *et al.*, 2000). Despite this, management and conservation of sharks has been largely reactive, proceeding only after marked declines in abundance and diversity have already occurred (FAO, 2000; Musick *et al.*, 2000). Such a situation is primed to occur in the Belize. Not only is shark exploitation largely unregulated and unmanaged, but only the whale shark, *Rhincodon typus*, is legally protected, a species that was never even part of the commercial catch. There is no National Plan of Action for sharks in Belize, as called for by the United Nations Food and Agriculture Organization, and there are no restrictions on the landing of sharks. The main fishing gear used for shark fishing is monofilament gillnetting, which is indiscriminant with regard to size and species and is also rapidly lethal to any captured shark. The reliance on this gear type currently makes it impossible to develop species specific shark legislation, as it would not be possible to catch and release alive any species that were prohibited from the fishery.

There are, however, some parts of Belize where the shark populations may be less impacted by fishing. Together with a few remote, lightly fished locations, the Belize Marine Protected Area Network may be among these because marine reserves within the network provide a spatial respite from fishing pressure. Glover's Reef Marine Reserve (GRMR) is one such location. In this paper, we will review our studies of the elasmobranchs of GRMR and other sites in central and northern Belize. The objective of this extended abstract is to describe the remaining elasmobranch biodiversity in this region.

MATERIALS AND METHODS

Glover's reef atoll (16° 44' N, 87° 48'W) lies approximately 25 km to the east of the Mesoamerican Barrier Reef and 45 km east of the Belizean mainland. The atoll is ~30 km from north to south and ~10 km at its widest. The reef crest partially separates the narrow fore-reef (<500 m in most areas) from the lagoon, which is basin shaped and as deep as 18 m. The forereef drops off nearly vertically at the reef slope, to depths of >400 m on the west side of the atoll and >1000 m on the east side of the atoll. Glover's Reef Marine Reserve (GRMR) was established in 1993 and is zoned for multiple uses. The southern third of the atoll is designated as a no-take zone, called the 'conservation zone', where no fishing is permitted. The rest of the atoll interior of the reef slope is zoned for restricted fishing where, among other regulations, commercial-scale shark fishing has been eliminated by a moratorium on the use of longlines and gillnets.

Between July 2000 and July 2011, we deployed several types of elasmobranch surveying gear at GRMR and several other sites in northern and central Belize (Turneffe atoll, Caye Caulker Marine Reserve and Southwater Caye Marine Reserve). Standard longlines and methods associated with handling, tagging, sampling and releasing elasmobranchs caught on this and the other gear are described in Pikitch *et al.*, (2005) and Chapman *et al.*, (2005). Since October 2007, we have deployed deep water longlines at depths of 250-400 m. Deep lines consist of a ¼ inch' nylon rope mainline that is set on the seafloor by a cement block tied to one end and suspended near vertically by a set of large floats tied to the other end. Five gangions were placed at 15 m intervals starting from the bottom, each one consisting of a tuna clip attached to 3.5 m of nylon line, a swivel and 3.5 m of stainless steel aircraft cable terminating in a baited 16 0/0 circle hook. Since 2009, we have deployed baited remote underwater video (BRUV) units to quantify the relative abundance of sharks between sites. BRUVs consist of a video camera (Sony Handycam DCR-HC52) inside an underwater housing that is mounted on a metal frame that has a small, pre-weighed bait source (1 kg of crushed baitfish) mounted on a pole in the camera's field of view. Sharks

are identified and counted as they swim into the field of view over the standard 70 minute deployment. Our final method of documenting elasmobranchs is opportunistic surveys of fishers and their catches in Belize City, Dangriga, Turneffe atoll, Glover's Reef atoll and Southwater Caye. One fisherman from Turneffe atoll provided us with a tissue sample from every shark he landed from June 2008-June 2011. We identified these samples to species using DNA barcoding (Wong *et al.*, 2009).

Results and Discussion

We documented 15 species of elasmobranchs at GRMR from 2000-2011. The dominant species are the nurse shark, *Ginglymostoma cirratum*, a demersal mesopredator, and the Caribbean reef shark, *Carcharhinus perezi*, an active top predator. Both species are common in the lagoon and fore-reef habitats. Nurse sharks also frequent shallow seagrass flats, while Caribbean reef sharks were recorded diving down the reef slope to depths of up to 352 m (Chapman *et al.*, 2007). Acoustic telemetry shows that both nurse and Caribbean reef sharks are mostly year round residents of GRMR (Chapman *et al.*, 2005, Bond *et al.*, submitted, Pikitch *et al.*, submitted). Caribbean sharpnose sharks, *Rhizoprionodon porosus*, are small demersal mesopredators that are also quite common in the lagoon. In contrast, lemon sharks, *Negaprion brevirostris*, an active top predator species, are now uncommon at GRMR. In the early years of the study we frequently observed and captured neonate lemon sharks on the seagrass flats around Middle Caye and Southwest Caye. Genetic studies showed that many of these were siblings, indicating that a relatively small number of adult females were using GRMR for parturition. From 2006 through to this year, we have not observed any neonates in these areas. However, in 2011 a group of at least 3 subadult lemon sharks has been frequently sighted at Middle and Northeast Cayes scavenging at fish cleaning stations. We have tagged and measured 2 of these at 189 and 193 cm TL (one male and one female). Southern stingrays (*Dasyatis americana*) and spotted eagle rays (*Aetobatus narinari*) are the most common rays at GRMR and can be found from shallow seagrass flats all the way to the edge of the reef slope. Both are mesopredators that feed on benthic invertebrates and small fish. All 6 of these shark and ray species are known to breed at GRMR, as we have captured specimens of every age class (neonate to adults of each sex). We have also observed a few specimens of yellow stingray (*Urobatis jamaicensis*) and captured 2 Caribbean whiprays (*Himantura schmarde*). These rays are also likely to be residents of GRMR, given its isolation.

GRMR also provides temporary habitat for several other migratory or highly mobile elasmobranchs. Over the course of the study we have captured 6 tiger sharks (*Galeocerdo cuvier*) ranging from 220-260 cm TL. We fitted 2 of these with coded acoustic transmitters. Both were detected at the capture site on the day they were released, but never after that. One was later detected sporadically on the other side of the atoll after a hiatus of ~150 days. Tiger sharks therefore appear to be transient at GRMR, although it is notable that we have only recently (from 2008) started regularly captured them on our standard longline sets. Great hammerhead sharks (*Sphyrna mokarran*) of ~200-400 cm TL are also occasionally observed at GRMR, but to date we have not captured or tagged any of them. On June 8, 2009, we captured and tagged the first blacktip shark (*Carcharhinus limbatus*) recorded at GRMR. The individual was a 184 cm TL female and therefore probably mature. Another notable capture in our survey was a juvenile Galapagos shark (*Carcharhinus galapagensis*). This was the first documented capture of this species in the western Caribbean and only the second verified capture in the whole Caribbean since 1963 (Pikitch *et al.*, 2005). Lastly, we are aware of at least one whale shark (*Rhincodon typus*) sighting at GRMR (Pikitch *et al.*, 2005).

Our deep water longline survey of the reef slope and pelagic habitat around Glover's Reef has revealed several additional species using the atoll. The most notable captures have been night sharks (*Carcharhinus signatus*), a relatively large mesopelagic species that had never before been recorded in Mesoamerica. We discovered that adults of this species form large aggregations at certain locations around Glover's Reef in 200-400 m depth. Twelve individuals have been captured, ranging in size from 197 to 249 cm TL (6 females, 6 males). Deep lines have also captured 3 silky sharks, *Carcharhinus falciformis*, a large epipelagic species, ranging in length from 221 to 286 cm TL (2 males, 1 female). Lastly, we have recorded 5 adult specimens of the smooth dogfish (*Mustelus canis insularis*) at depths of 200-400 m off the reef slope from fisheries catches. We hypothesize that there is a rich demersal elasmobranch fauna at these depths, but we have not yet set our lines in such a way to capture them over concerns about causing mortality and/or losing gear.

The elasmobranch fauna of Turneffe atoll is generally similar to that of GRMR in terms of species composition and diversity (16 species). Nurse and Caribbean reef sharks dominated our standard longline surveys in 2005 and 2006, where we also captured Caribbean sharpnose sharks, southern stingray, blacktip sharks, lemon sharks and Caribbean whiprays. Our survey of the catches of one net fisher at Turneffe from 2008-2011 indicate that Caribbean sharpnose and Caribbean reef sharks are the main commercial species, followed by blacktip, lemon and great hammerhead sharks. These three last species all appear to be more common at Turneffe atoll than Glover's, which probably reflects habitat differences between these sites. Turneffe has much more extensive mangrove forest than Glover's Reef, which means that Turneffe is more likely to serve as a nursery for these shark species. We also observed scalloped hammerhead (*Sphyrna lewini*) and bull sharks (*Carcharhinus leucas*) in the net catches, although much less frequently than the other species. We have been shown numerous underwater photographs of aggregations of large scalloped hammerheads taken off the southern end of Turneffe. All net-captured scalloped hammerheads were small, which indicates that this area serves as both juvenile habitat and an aggregation area for adults.

We have also surveyed fisheries catches in Belize City, Dangriga and Southwater Caye Marine Reserve opportunistically since 2000. In Pikitch *et al.* (2005), we reported the following composition from Belize City and Dangriga fishmarket collections: 'Shark collections at the 2 coastal fish markets yielded a total of 57 intact specimens, consisting of 30 blacktips *Carcharhinus limbatus* (18 neonates, 12 juveniles <90 cm TL), 2 *Negaprion brevirostris* (1 neonate, 1 juvenile 156 cm TL), 22 bonnetheads *Sphyrna tiburo* (all juveniles <60 cm TL), 1 scalloped hammerhead *S. lewini* (neonate), 1 great hammerhead *S. mokkaran* (juvenile <90 cm TL), and 1 *Rhizoprionodon porosus* (neonate). Discussions with fishers indicated these were all captured inshore on the coastal side of the barrier reef between Dangriga and Belize City. Since that report we have observed that juvenile blacktips, adult Caribbean sharpnose are still observed in these two markets. We have observed more Caribbean reef and nurse sharks in Belize City from 2005 to the present and have observed no bonnetheads at all. On January 25, 2011 in Southwater Caye Marine Reserve, we sampled recent catches of a gillnetter that fishes the area. We found 5 fin sets from large great hammerhead sharks, as well as ~ 20 fin sets from juvenile Caribbean reef sharks.

Our surveys reveal that the parts of Belize we sampled retain a reasonably diverse elasmobranch fauna (at least 18 species) and possess large tracts of important habitat for them. However, there is evidence that fishing is severely impacting shark populations. Our BRUV deployments show that there are significantly fewer Caribbean reef shark observed on fished reefs (Turneffe, Southwater Caye prior to reserve establishment) than the marine reserves GRMR and Caye Caulker (Bond *et al.*, submitted). Many of these species rely on the Barrier Reef and associated seagrass and mangrove forests as juvenile habitat. At least one of the offshore atolls, Glover's Reef, is an important refuge from fishing for several shark species. Given the potentially precarious state of shark populations in Belize, we suggest that additional anthropogenic stressors affecting these habitats could greatly accelerate fisheries-induced population declines. Oil exploration and potential spills from drilling are two potential stressors that could seriously impact these habitats and the shark populations that rely on them.

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SNAPPER AND GROUPER ASSEMBLAGES OF BELIZE: POTENTIAL IMPACTS FROM OIL DRILLING[1]

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ABSTRACT

The grouper/snapper species complex is made up of top predators within coral reef ecosystems and together is the most commercially important group. As top predators, they are also indicative of the health of coral reef systems. This paper summarizes nearly 20 years of research on the life history of snappers and groupers in Belize, with a focus on spawning aggregations, larval transport, and juvenile settlement and development in nursery areas. The contribution then addresses the possible impacts of oil on the various life stages and habitats utilized by snappers and groupers. Though the likelihood of spill or contamination from oil exploration and development may be very small, the potential effects of such events are so catastrophic that the risk may outweigh the potential benefits.

INTRODUCTION

Coral reef ecosystems, along with tropical rain forests are the most biologically diverse ecosystems on earth. These systems contribute to regional economic and ecological health in many ways including fisheries productivity, marine tourism, and coastal protection from storms. The snapper/grouper complex includes many of the reef's top predators and serves as indicators of ecosystem health. The Belize Barrier Reef System is the largest in the hemisphere, the second largest in the world, and is locally and internationally recognized for its cultural, ecological, and economic values (IUCN World Heritage Site Designation).

Snappers and groupers share similar life history characteristics—starting their juvenile period in seagrass and mangrove habitats, migrating into shallow patch reefs, and after 3-6 years reach reproductive maturity (see contributions in Arreguín-Sanchez *et al.*, 1996). They then spawn in aggregations at predictable times and places, releasing pelagic eggs that are fertilized in the water column. After 12-24 hours, the eggs metamorphose into larvae, which swim in the plankton for 1 to three weeks and then settle as juveniles into protected nursery habitats, generally mangroves and seagrass. While there are many variations on this general pattern, most

Figure 1. The locations of 14 multi-species reef fish spawning aggregation sites in Belize. The sites all occur at sharp bends in reefs otherwise referred to as reef promontories (after Figure 1 in Kobara and Heyman, 2010).

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commercially important groupers and snappers in Belize (e.g., mutton snapper, cubera snapper, yellow tail snapper, Nassau grouper, black grouper, yellowfin grouper, tiger grouper) can be described this way. The goals of this paper are to: 1) summarize recent research and provide further details on the timing and location of spawning aggregations; 2) discuss the value of these fishes and the ecosystems on which they rely to the local and national economy; and 3) discuss the possible effects on these systems from oil exploration and development.

RESULTS AND DISCUSSION

With the support and collaboration of the Belize National Spawning Aggregations Working Committee, we have participated in research that characterizes multi-species reef fish spawning aggregations in Belize. In short, aggregations of multiple reef fish species aggregated to spawn at specific times and places that can be explained by the 'multi-species promontory' hypothesis which states: Large and commercially important reef fishes in the Caribbean typically spawn in large aggregations at shelf edges (25-40 m water depth) and reef promontories (relatively sharp bends in the shelf) adjacent to deep water (>200 m) (Figures 1 and 2). These aggregations occur at predictable times and places for each species according to seasonal, lunar, tidal, and diel cycles—with grouper spawning in Belize occurring around sunset, 4-12 days after full moon from December-March and most snapper spawning occurring around sunset, 2-8 days after full moon from March-June and a smaller peak August-September (Figure 3). These data are detailed and summarized in a series of recently published scientific papers (Heyman *et al.*, 2001; 2005; Heyman and Kjerfve, 2008; Kobara and Heyman, 2008; 2010).

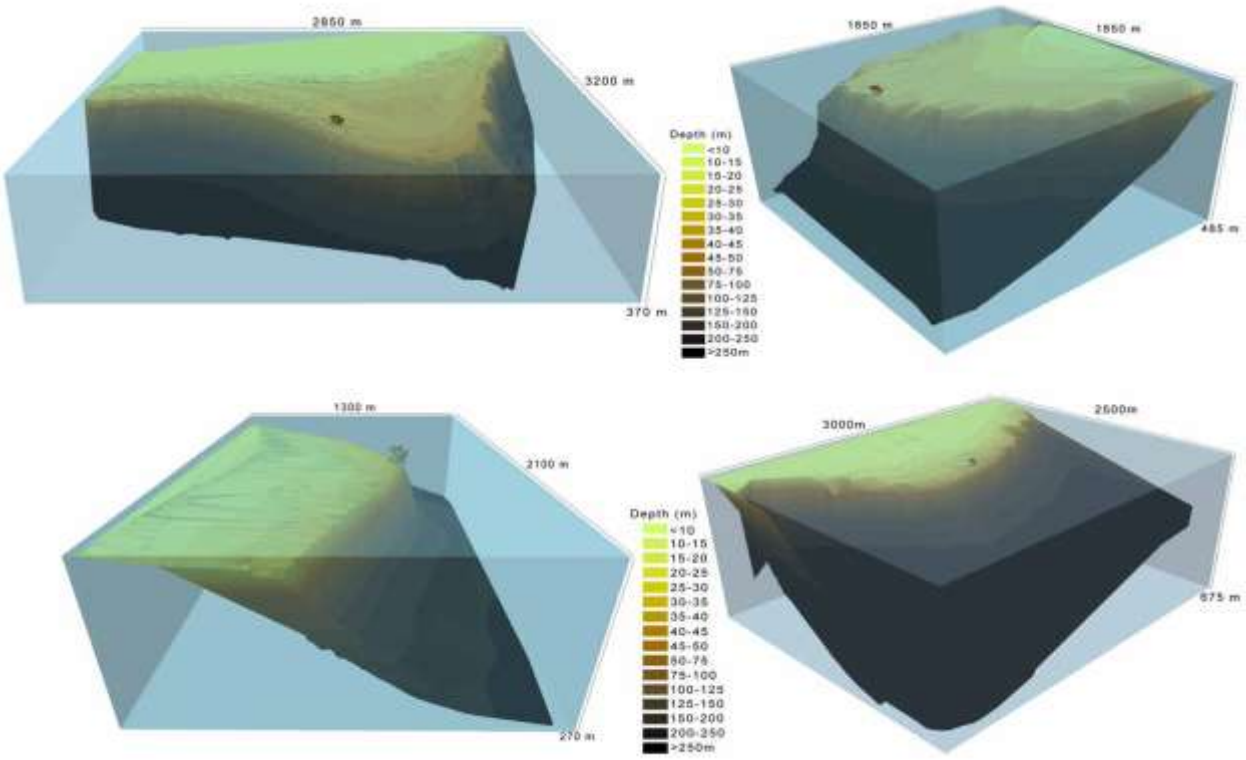

Figure 2. Geomorphology of Gladden Spit, perhaps the best studied multi-species reef fish spawning aggregation site in the world, and representative of other sites in terms of geomorphology and species composition. The figure shows the location of the aggregations (fish symbol) at the promontory tip, along the shelf edge (30 m water depth) adjacent to deep water (>200 m; from Heyman and Kobara, 2011).

From 1998 to the present, the Belize National Spawning Aggregations Working Committee has described and monitored between 9 and 12 multi-species reef fish spawning aggregations throughout Belize. They also worked as a coalition to protect these sites, which were declared as no-take marine reserves in 2002, along with legislation to protect the endangered Nassau Grouper (Gibson *et al.*, 2007). Importantly, the legislation to protect these sites was fully supported by the great majority of commercial fishers, including those who have traditionally fished the spawning sites. Their support came from their understanding of

the value of the spawning sites to the long-term health of the stocks and the reef. They gained this understanding in part, through their intensive participation in the research program that described the sites. Their support was likely increased by their access to training in economic alternatives to fishing, such as SCUBA and snorkel ecotourism guiding, provided by members of the Spawning Aggregations Working Committee (especially TIDE, SEA, and Green Reef; Heyman, 2011).

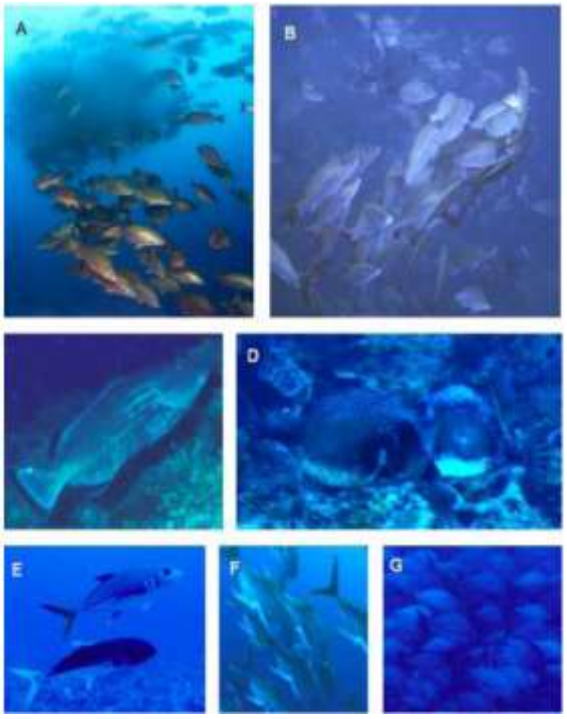

Figure 3. Gladden Spit has at least 17 species of fish from nine families that aggregate to spawn including: (A) Dog snapper, *Lutjanus jocu* spawning event in late afternoon (B) Mutton snapper, *Lutjanus analis* releasing gametes in a group spawning event in mid afternoon, (C) Black grouper, *Mycteroperca bonaci*, shown here in courtship coloration, (D) Smooth trunkfish, *Lactophrys triqueter* showing courtship behaviour and coloration, (E) Horse-eye jack, *Caranx latus, in* courtship coloration, (F) Jack crevalle, *Caranx hippos* showing courtship coloration, (G) White margate, *Haemulon album* aggregation in mid afternoon (adapted from Figure 3 in Heyman and Kjerfve, 2008).

Figure 4. Life cycle of Cubera snappers (representative of the grouper snapper complex) include various stages and habitats (shown clockwise from upper left): A) adult spawning aggregations which occur at reef promontories (photo by Douglas David Seifert), B) fertilized eggs which float in the plankton for 18 hours (photo by Carol Farnetti Foster), C) planktonic larvae which start feeding after four days and often drift or swim inshore, and D) juveniles that settle and live in seagrass and amongst the shallow prop roots of red mangroves.

The most vulnerable period in the life history of most groupers and snappers occur during the egg and larval phases (Figure 4). These delicate stages are far more susceptible to changes in water quality and/or toxicity. Studies of the impacts from oil drilling, exploration or spillage should be conducted on these stages, rather than on the adults, which may have the ability to simply swim away. The effects of oil, drilling muds, and dispersants have been evaluated for many marine and coastal fish species and the results are uniformly negative and significant. The larval and early juvenile phases of most organisms, including fishes, are highly vulnerable to even the slightest concentrations of oil-derived pollutants and dispersants (Wilson, 1977; NRC, 2005; Tunnel, 2011).

The value of reef fish spawning aggregations cannot be overstated. They include the most important and most vulnerable stages in the life cycle of most commercially important reef fishes. The adults are most vulnerable to fishing at these predictable times and locations and the eggs and juveniles are highly susceptible to contamination. The value of these aggregations therefore includes the value of the fish in a healthy fishing industry. The value also includes the existing and potential ecotourism on these dramatic events. Recent work has illustrated that the value of spawning aggregations for ecotourism far exceeds

their value in commercial fisheries (Sala *et al.*, 2001). Further, dive ecotourism does not appear to negatively affect the fishes' courtship or spawning behaviour (Heyman *et al.*, 2010). As Belize has the best well documented and dramatic reef fish spawning aggregations in the world, ecotourism on spawning aggregations represents significant and relatively untapped, sustainable tourism development potential.

CONCLUSION

Are the risks of oil drilling worth taking? If well managed, there is a very low probability of large spills and accidents in oil drilling, exploration and development. But, in the unlikely event that such a spill does occur, there will likely be catastrophic effects on coral reef ecosystems. The long term economic and employment benefits from fisheries and tourism industries that can persist with a healthy coral reef system will be significantly degraded by an oil spill. However, small the risk, and however large the economic gains from oil extraction, the risk of the catastrophic damages that will ensue are probably not worth taking.

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ENDEMIC MARINE FISHES OF BELIZE: EVIDENCE OF ISOLATION IN A UNIQUE ECOLOGICAL REGION[1]

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ABSTRACT

The Meso-Amercian Barrier Reef (MABR) forms a physical boundary enclosing a large coastal lagoon that runs the length of the country of Belize. This creates a semi-enclosed body of water that is a mix of oceanic water and freshwater river input. Thus, the Belize lagoon ecosystem is unique in the western hemisphere and represents a distinct biogeographical province with special water quality. The majority of coral reef fishes have pelagic larvae that spend weeks in the plankton during their early development. This is a highly dispersive phase of the life history of marine fishes. As a result, most Caribbean species range throughout the Caribbean Sea. Even so, some taxa show strong local selection and restricted biogeographic distributions. In Belize, this is especially evident and probably due in large part to the physical barrier of the reef and the special quality of the marine water in the lagoon system. Recent studies of the fishes inside the MABR have discovered several new species of fishes and many of these are endemic to Belize. A preliminary estimate of endemic fishes in Belize yields a count of 12 species found only in the lagoonal area and another 8 species found on the outer barrier reef and the atolls.

INTRODUCTION

Belize is in a corner of the Caribbean Sea that is bounded by unique oceanographic conditions and the distinctive barrier reef. The majority of fishes that occur in Belize are the same species that are found everywhere else in the Caribbean. But, there are exceptions; there are some species found only in Belize and nowhere else. These are scientifically designated as 'endemics'. The endemic marine fishes of Belize are evidence of biological isolation in a unique ecological region. The biological questions are 'what local ecology are these endemic fishes adapted to?' and 'how do these species maintain their genetic uniqueness?' Such questions are complicated and require learning the details about the fish's natural history. Many marine animals have early life histories as embryos and small larvae which drift in the plankton. These animals spawn free floating eggs and their offspring drift away. As such, these propagules are easily dispersed over vast distances creating large populations of single species. Such is the case for many of the most familiar fishes such as groupers, snappers, surgeonfishes and many other reef fishes. But, some other fishes have evolved different reproductive tactics that result in their planktonic larvae staying close to natal reefs. Some of these fishes have developed non-dispersing embryos and larvae and others have adapted their reproduction and larval dispersal to occur during times when oceanographic conditions entrain and retain the larvae near home reefs. The Belize Barrier Reef System is a semi-enclosed marine habitat. Even though it does pulse with tides and there is an influx of oceanic waters through myriad channels. The bulk of the water inside the Barrier Reef has a higher retention or residency time than it would have otherwise if that barrier reef was not present.

It is important to describe biogeographically restricted species for purposes of conservation and as key indicator species used in ecological monitoring for local effects. To date, there have been about 500 fish species found in Belize waters (see Palomares and Pauly, this volume). David Greenfield pioneered ichthyological surveys in Belize in the 1970s. Subsequently scientists from the Smithsonian museum have been the leading force in documenting Belize reef communities and describing new species (e.g. Baldwin, Faust, Lavett-Smith, Ruetzler, Tyler and others).

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This report highlights the several new fish species that we have found in Belize with help and collaboration of colleagues. Big fishes are easier to find than little fishes. The new discoveries that we are making of previously unknown species in Belize waters have one key common trait. The new fishes are small and easily overlooked or mistakenly misidentified. In some cases, it required DNA data combined with color photographs of live fish to make the case distinguishing the Belize population as a distinct species.

Cleaner Goby, ***Elacatinus lobeli*** (Randall and Colon, 2009). This species is similar in color to the neon goby found in Florida, but it is genetically and morphologically distinct. It is a cleanerfish and removes ectoparasites from host fishes. It is endemic to the MABR, and is found broadly inside the MABR and on the atolls. It was named for Phillip S. Lobel who photographed and collected type specimens.

This probable new species of **Banner Goby, *Microgobius*** is found only in deep sand flats areas (>15 m) in the inter-reefal channels between mangrove islands in Belize MABR. It is very hard to see as it prefers murky water, is very skittish and avoids divers. This species is being diagnosed for description by the authors with J. Randall.

Sponge Goby, ***Elacatinus coloni*** (Randall and Lobel, 2009). This species is a sponge dweller and feeds on a polychaete sponge parasite. It is endemic and found only inside the MABR usually in tube sponges.

Atoll Goby, ***Elacatinus* nov. sp.** (Lobel and Kaufman, *in prep.*). On their first scuba dive at Lighthouse Atoll, Lobel and Kaufman discovered this new species! This was the weekend before the February 2010 MMAS meetings (Belize City). We returned to the atoll after the meetings and collected the type specimens. It has blue stripes similar to *E. lobeli* but this new fish is distinct by having a white-ish nose spot and is only found at deeper depths (>30 m).

The **'Maya hamlet'** is a new species of ***Hypoplectrus*** found only in Belize. The manuscript describing this species is in press (Lobel, 2011).

The **Social wrasse, *Halichoeres socialis*** Randall and Lobel, 2003. Male and female (in back). This new Belize fish species was discovered during the Lobels' first field trip to Belize in 1993. Continued study of its biology and biogeographic distribution is an annual project conducted by students in Professor P.S. Lobel's coral reef ecology field course, Boston University Marine Program.

A preliminary listing of marine fishes with distributions mainly within the MABR system including the outer reef and atolls is presented in Table 1. A few of these species (e.g., *E. lori, T. clarkii, T. briggsi*) possibly range as far as the Bay Islands, Honduras, which are nearby the southern margin of the MABR. More research is needed to better define the biogeography of these species.

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Table 1. Preliminary listing of marine fishes with distributions mainly within the MABR system including the outer reef and atolls. Species whose distribution is so far known only from the lagoons inside of the MABR are noted with an asterisk (*).

Family	Genus and species	Reference
Batrachoididae	*Sanopus greenfieldorum* *	Collette 1983
	Triathalassothia gloverensis	Greenfield and Greenfield 1973
	Opsanus dichrostomus *	Collette 2001
	Sanopus astrifer	Robins and Starck 1965
Chaenopsidae	*Acanthemblemaria paula* *	Johnson and Brothers 1989
	Emblemariopsis ruetzleri *	Tyler and Tyler 1997
	Emblemariopsis dianae *	Tyler and Hastings 2004
Gobiesocidae	*Tomicodon lavettsmithi* *	Williams and Tyler 2003
	Tomicodon clarkei	Williams and Tyler 2003
	Tomicodon briggsi	Williams and Tyler 2003
Gobidae	*Elacatinus coloni* *	Randall and Lobel 2009
	Elacatinus lobeli	Randall and Colin 2009
	Elacatinus lori	Colin 2002
	Elacatinus sp nov	Lobel and Kaufman ms
	Microgobius sp nov *	Lobel, Lobel and Randall ms
	Psilotris amblyrhynchus	Smith and Baldwin 1999
Blennidae	*Starksia weigti* *	Baldwin *et al.* 2011
	Starksia sangreyae *	Baldwin *et al.* 2011
Serranidae	*Hypoplectrus* sp nov *	Lobel *et al.* 2009, Lobel in press
Labridae	*Halichoeres socialis* *	Randall and Lobel 2003

New species of invertebrate found in Belize, December 2010. P. Lobel found this undescribed phoronid worm in the muddy bottom habitat in deep channels between cays in the lagoon. In February 2011, Lobel returned with Prof. G. Giribet (Harvard) and collected specimens. The description of this new species is in preparation. The worm has a burrow in the sand and it will extend itself about 5 cm above the surface, but retracts when disturbed. It is one of only about 12 species of this kind of phoronid worldwide and one of the few tropical ones.

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FUNCTIONAL IMPORTANCE OF BIODIVERSITY FOR CORAL REEFS OF BELIZE[1]

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ABSTRACT

A thriving coral reef results from an intricate collaboration among many different kinds of animals, plants, and micro-organisms. Some of the key collaborators include nearby seagrasses and mangroves that capture and control sediments and transform dissolved nutrients into plant biomass, and herbivorous fishes and sea urchins that prevent quickly growing algae from overwhelming reefs. But most central to the building and maintenance of the reefs are corals and sponges, and the microbial collaborators that live within their bodies. Reef-building corals deposit solid carbonate skeletons as they grow, building a sturdy 3-dimensional framework within which fishes, crustaceans, and other animals shelter and find food, while sponges glue living corals onto the reef frame and protect them from excavators, facilitate regeneration of damaged reefs, and keep the water clear by efficiently filtering bacteria and phytoplankton. All of these functional roles must be played for a reef to remain healthy and capable of recovering from damage.

Coral reefs, as shallow-water tropical ecosystems, have always been challenged by physical damage due to hurricane-charged water movement, and more recently, by pulses of freshwater and sediment due to heavy coastal rains, and temporarily extreme temperatures. Recovery from effects of these challenges is a normal part of the dynamics of healthy coral reefs. High species diversity of corals and sponges is essential to successful recovery because species differ in their ability to: a) resist challenges (physical disturbance, disease, high or low temperatures, sediment, etc.), b) recover from challenges (by regeneration, regaining symbionts after bleaching, halting the advance of disease, etc.), c) recover in the sense of recolonization by the next generation, and d) host symbionts and engage in other interactions that increase survival of participants. As well, individuals within a species vary in their ability to resist or recover from challenges and to interact positively with other organisms. When high biodiversity is protected, there are always at least some species capable of performing each of the roles essential to the functioning of the reef - even when other species are temporarily diminished by their vulnerability to a particular environmental challenge. However, when multiple challenges occur together, or when the challenges are novel (i.e., exposure to substances that humans have manufactured or released from inside the earth), too many species may be diminished or deleted simultaneously, impairing the natural growth and recovery processes.

INTRODUCTION

Coral reefs, as shallow-water tropical ecosystems, have always been challenged by physical damage due to hurricane-charged water movement, and more recently by pulses of fresh-water and sediment due to heavy rains on deforested coasts, and temporarily extreme temperatures. Recovery from effects of environmental challenges is a normal part of the dynamics of healthy coral reefs. High species diversity of corals and sponges is essential to successful recovery because species differ in their ability to: a) resist challenges (physical disturbance, disease, high or low temperatures, sediment, etc.); b) recover from challenges (by regeneration, regaining symbionts after bleaching, halting the advance of disease, etc.); c) recover in the sense of recolonization by the next generation; and d) host symbionts and engage in other interactions that increase survival of participants. As well, individuals within a species vary in their ability to resist or recover from challenges and to interact positively with other organisms. When high biodiversity is protected, there are always at least some species capable of performing each of the roles essential to the functioning of the reef—even when other species are temporarily diminished by their vulnerability to a particular environmental challenge. However, when multiple challenges occur together,

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or when the challenges are novel (i.e., exposure to substances that humans have manufactured or released from inside the Earth, such as oil), too many species may be diminished or deleted simultaneously, impairing the natural growth and recovery processes.

CORALS AND SPONGES

Corals and sponges spend their adult lives attached to the substratum on which they settle as waterborne larvae, and they illustrate great variety in shape and size, facility at asexual propagation and regeneration, and tendency to host microbes within their bodies. Corals and sponges differ from each other in important ways that underlie the compatible roles they play in building, maintaining, and repairing coral reefs.

Corals

Corals deposit rock-like calcium carbonate skeletons as they grow, creating the basic building blocks of the reef structure. Among the 45 reef-building corals inhabiting the Belize Barrier Reef (Bright and Lang, 2011) are a great variety of shapes, including branching, plate-shaped, pillar, massive mounds, and encrusting forms. Whatever the overall shape of a colony, the living tissue is always a very thin layer over the surface. Thus even shallow wounds expose skeleton, making it vulnerable to colonization by quickly growing algae that can inhibit regeneration, and also by excavating organisms which can bore into the solid carbonate of the coral skeleton, weakening its attachment to the reef frame. Although coral polyps can capture plankton with their tentacles, they acquire most of their food from the single celled algae, called zooxanthellae, that live at high densities within their tissue. Like all plants, zooxanthellae convert sunlight energy into food energy. Their position within the corals enhances their access to nutrients due to recycling of metabolic wastes. Although this collaboration is unquestionably beneficial to the corals, as their chief food source, dependence on zooxanthellae makes corals vulnerable to the possibility that the association may break down under stressful environmental conditions. In particular, abnormally high sea surface temperatures cause zooxanthellae to be expelled by their coral hosts. Moderation of temperatures can allow recolonization of corals, but bleaching can weaken corals, making them more vulnerable to other threats such as diseases. If zooxanthellae are unable to recolonize quickly, the corals die.

Sponges

Most of the over 800 species of sponges (Diaz and Rützler, this volume) that inhabit Caribbean coral reefs and associated habitats have soft bodies with living tissue throughout. Their skeletons, which homogeneously pervade the living tissue, are made of fine meshworks of protein fibers, generally augmented by silica spicules. Sponges are also pervaded by a system of canals through which they pump water, from which they filter bacteria and other very small particles extremely efficiently. The extraordinarily simple internal structure of sponges bestows on them great flexibility in growing around obstacles, adjusting to changes in orientation, and accommodating close associations with other organisms. Because sponges are living tissue throughout, wound healing can be achieved quickly, by simply reconstituting the layer of specialized cells that cover the surface; thus sponges are masters of regeneration after damage or fragmentation (Wulff, 2011).

ROLES OF CORALS AND SPONGES IN BUILDING, MAINTAINING, AND REPAIRING CORAL REEFS

Growth of corals is required for generating the solid carbonate building blocks of reef framework. But, even as they accrete, coral skeletons are also eroded by grazing fishes and sea urchins, and by a handful of bivalve and sponge species that transform solid carbonate to fine sediment, as they excavate burrows for themselves. Excavations can erode coral basal attachments to the point that corals relinquish their grip on the reef frame, often perishing in the surrounding sediments or cascading into deeper water. Fortunately, sponges associated with corals can increase coral survival by gluing them to the reef frame. Experimental removal of sponges from fore-reef patches resulted in 40% of the corals becoming disengaged from the reef frame; while on similar patch reefs with intact sponges coral mortality was only 4% (Wulff and Buss, 1979). This collaboration of solid rock-generating corals with sponges capable of adhering corals to the reef frame is further enhanced as the sponges filter the entire water column above the reef each day, maintaining water clarity that allows corals to receive adequate sunlight for their zooxanthellae.

Physical damage to coral reefs, on scales ranging from small patches to many square kilometers, is inevitable given the coincident geographic distribution of coral reefs and tropical storms. The ability to recover is a normal part of the life histories of coral and sponge species, and repair and regeneration is a

normal part of coral reef growth. At any moment portions of a reef system have been recently damaged by a storm, so the process of regeneration of rubble mounds into solid reef frame onto which living corals can flourish once again is required for continued growth of coral reefs to keep pace with rising sea level. Large pieces of damaged or dead coral may remain stable where they fall at the end of a storm, but smaller rubble pieces can continue to be churned by foraging fishes or water motion, impeding their incorporation into a stable structure. Coral larvae that settle on loose rubble tend to be smashed, as rubble pieces are moved against each other. Because sponges can adhere quickly to solid carbonate with any part of themselves, the same gluing capability that allows them to bind living corals to the reef frame also allows them to bind piles of loose rubble into continuous structures. Once loose rubble pieces are stabilized, crustose coralline algae can grow from one piece of rubble to the next, cementing them together, rendering them more hospitable to small corals (Wulff, 1984). Sediment generated by grazing and excavating organisms fills in the holes in the frame, increasing solidity. Growth of corals continues the cycle.

Tropical storms have challenged coral reefs as long as they have existed, but additional challenges have been increasing in importance: pulses of freshwater and sediment running off of deforested land, bleaching due to increased sea surface temperatures, coral predators that are no longer kept in check by their larger predators that have been overfished, and diseases that are poorly fended off by animals that are stressed by other challenges. Each of the many species of corals and sponges that participate in reef building and re-building is characterized by a unique set of strengths and vulnerabilities, and no single species is the best at coping with all environmental challenges. Species that rebound gracefully after a storm may succumb to disease, while species that resist bleaching may be overwhelmed by uninhibited predators, and those most resistant to predators may be devastated by storms. In the following section, examples illustrating the wide range of variation in resistance to and recovery from a few of the challenges faced by sessile animals on reefs are drawn from the diverse species inhabiting the Belize Barrier Reef.

VARIATION AMONG SPECIES IN RESISTANCE TO, AND RECOVERY FROM, CHALLENGES

Physical damage by storms

Massive corals, such as *Montastraea* species, are champion survivors of hurricanes, remaining standing amidst a litter of fragments of branching species and broken off corals with small basal attachments. Branching species of both corals and sponges, although readily broken tend to be especially adept at recovering from breakage, as fragments can reattach to the substratum, and branching patterns adjust to their new orientation as fragments continue to grow. Thus moderate storms can result in propagation, but the violent water motion of major hurricanes can overdo breakage to the point of destruction (e.g., Woodley *et al.*, 1981). Corals with smaller forms and shorter life spans may be readily damaged by storms, but tend to be successful at replenishing their populations by efficient settlement of larvae (e.g., Bruckner and Hill, 2009).

Sponge species also balance resistance to damage with recovery in a variety of ways. After Hurricane Allen in Jamaica in 1980, monitoring of nearly six hundred sponges over 5 weeks for recovery revealed an inverse relationship between ability to resist damage and ability to recover from damage (Woodley *et al.*, 1981; Wulff, 2006b). Erect branching species suffered the most damage, but they were also most adept at recovering; while at the opposite extreme, many sponges of species that live confined to cryptic spaces within the reef frame eluded damage altogether in their protected microhabitat; however, those that were exposed as the framework was ripped apart did not recover at all. Massive sponges with tough skeletons were highly resistant to being damaged, but when they were damaged, recovery was ilusive. These massive, tough species were able to recoup their substantial losses, however, by recolonizing the battered reefs with their next generation (Wilkinson and Cheshire, 1988).

Bleaching

Variation in susceptibility to bleaching varies with the coral species, clade of zooxanthellae hosted, and habitat details (e.g., Baker, 2003). Variation among species can be extreme, as in a 2005 bleaching event during which 85% of colonies of the relatively small massive coral *Porites astreoides* were resistant, but fewer than 5% of the colonies of the large massive corals in the *Montastraea annularis* species complex remained unbleached (Bruckner and Hill, 2009). Closely related coral species can differ in vulnerability, for example the plate-shaped *Agaricia agaricites* tends to be able to cope with higher temperatures better than closely related *Agaricia tenuifolia* (Robbart *et al.*, 2004). The net result of bleaching is a combination

of susceptibility to bleaching and ability to recover. Ultimate results of very similar rates of severe bleaching in the brain coral *Colpophyllia natans* and the short thickly branched *Porites porites* (92% and 97% of colonies, respectively) were very different, with 88% of completely bleached *Colpophyllia* recovering, but only 28% of completely bleached *Porites* recovering (Whelan *et al.*, 2007). Individuals within a species also vary in their ability to cope with environmental challenges. In the case of species that are capable of propagation by fragmentation, it is possible that relatively resistant genotypes will be able to quickly increase in abundance. Genotypes of staghorn and elkhorn coral that have demonstrated particular resistance are currently being propagated in nurseries in Laughing Bird Caye National Park, Belize, in order to bolster natural replenishment of reefs (Carne, in press).

Disease

Coral diseases are not generally specific to a single species, but there are patterns in the tendency of a particular disease to affect certain corals (Bruckner, 2009), complicated by the recent history of bleaching and other weakening circumstances. For example, the ultimate fates of the *Porites porites* and *Colpophyllia natans* colonies in the bleaching recovery study mentioned in the previous paragraph were high mortality all around, because the *Colpophyllia* colonies that recovered from bleaching succumbed to White-plague type II disease (Whelan *et al.*, 2007). Diseases have disproportionately influenced populations of some of the most important and abundant Caribbean reef coral species. The near demise of the *Acropora* species, staghorn and elkhorn corals, that contributed rapid growth and facile recovery from damage to shallow reef zones, has been attributed to white band disease; and populations of the large, long-lived massive *Montastraea* species, so highly resistant to physical damage, have been heavily influenced by yellow band and white plague diseases. Short-lived, smaller-colony species have been less affected (e.g., Bruckner *et al.*, 2009). Sponge diseases by contrast tend to be quite specific to particular species. Disease may be having a profound effect on sponge species diversity. By the end of a 14 year study on a shallow reef at a remote site, 20 of the 39 sponge species present at the start had vanished, with disease the most likely culprit (Wulff, 2001, 2006a).

CONCLUSIONS

Complementary roles played by corals and sponges in reef building, maintenance, and repair are all required to the point that if any are not performed, the entire enterprise can fail. But, why do we need to be concerned about keeping more than a few species of each alive and well? Species of corals and sponges that build, maintain, and repair coral reefs have evolved in a context that has provided the selective impetus for an effective balance between resistance to, and recovery from, physical disturbance by tropical storms. Species less resistant to damage make up for that by effective individual recovery by regeneration or by population level recovery by recolonization. When threats are relatively novel, as are bleaching and disease, strategies that compensate for lack of resistance are much less evident, perhaps reflecting the lack of time for evolution in response to these threats. Species that appear especially vulnerable are failing to exhibit effective recovery.

Oil is not a substance to which corals and sponges have had a chance to evolve strategies for either resistance or recovery. In 1986, an oil spill in Bahia las Minas, near the Caribbean terminus of the Panama canal, killed many corals outright, resulting in an immediate decrease in coral cover by 76% at 3 m depth or less, and 45% at 9 to 12 m depth (Jackson *et al.*, 1989). After 5 years, recovery was still not apparent. Corals on oiled reefs had slower growth and higher injury rates, and there was practically no recruitment of the next generation (Guzmán *et al.*, 1994). Effects of oil on sponges are much less understood, in large part because sponges vanish so quickly after they are killed that they are invisible to any monitoring that is not immediate. Highly efficient filtering of large volumes of water may render sponges especially vulnerable to oil that has been broken into fine suspended droplets with chemical dispersants. Lingering effects of the Panama oil spill were in part due to continual re-oiling, every time sediments in which oil had become buried were resuspended by water movement (Levings *et al.*, 1994).

High biodiversity ensures functional redundancy of species that differ in how gracefully they cope with temperature extremes, disease, and physical damage so that there are always at least some species capable of performing each of the roles essential to the functioning of the reef - even when other species are temporarily diminished by their vulnerability to a particular environmental challenge. However, when multiple challenges occur together, or when the challenges are novel, as oil is, too many species may be diminished or deleted simultaneously, impairing the natural growth and recovery processes. Given the

inability of slow-recovering species to resist novel threats, it seems rash to risk the addition of oil to the many other threats currently facing corals and sponges of the Belize Barrier Reef.

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BIODIVERSITY OF SPONGES: BELIZE AND BEYOND, TO THE GREATER CARIBBEAN[1]

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ABSTRACT

Sponges represent one of the most diverse benthic faunal groups in subtidal habitats of Caribbean coral reefs and mangroves. On coral reefs, sponges (100-261 species) surpass the species richness of other conspicuous reef organisms, such as octocorals (60-80 species) and scleractinian corals (50-60 species). In the past 35 years, researchers supported by the Caribbean Coral Reef Ecosystems program (Smithsonian Institution) have produced more than 125 publications about marine sponges. These studies have covered many disciplines, including traditional morphological descriptions of new species, but also developmental biology, ecology, symbioses, disease, and evolutionary analyses revealing population affinities throughout the Caribbean using DNA fingerprinting. Various studies have shown that the Belizean corals reefs and mangroves harbor the third richest sponge fauna in the greater Caribbean (after Cuba, and the Florida peninsula). Comparisons between reef and mangrove faunas show that, throughout the Caribbean, they are consistently distinct in their species composition. Many more species will be discovered once the less accessible habitats, such as mesophotic reefs and deeper hard bottoms, are explored.

The importance of sponges as a marine resource in Belize is substantial, with respect to services relevant to both their own communities and the human domain. First, they are well known as unique biological pumps and filters, due to great living biomass combined with high water filtration capacity (up to 1 liter per cubic-centimeter sponge per hour), and to complex bacterial assemblages living symbiotically in their bodies (cyanobacteria, nitrifying bacteria, archaebacteria). Secondly, a varied morphologic diversity (shape and color), some with large sizes (up to several meters in diameter), makes them one of the most attractive and intriguing creatures to the curious sport diver visiting Belizean coral reefs. Some sponges are the main dietary component for marine turtles, and a food supplement for many reef fishes (butterfly fishes, angelfishes). Besides their nutritional benefit to sea turtles and fishes, they also provide habitats to hundreds of species of invertebrates and fishes living in cavities inside sponges. In mangrove habitats, too, we have found that sponges are diverse and abundant, particularly on stilt roots of red mangrove lining the tidal channels, and that they probably have developed a long-standing relationship with these plants, offering protection from root borers and possibly exchanging nutrients with them.

Besides their attractiveness to underwater tourism, sponges, together with algae and bacteria, are among the marine organisms with highest pharmacological potential for human use, mainly from secondary metabolites produced as defensive chemicals. This well-known capacity makes them a unique resource that must be protected for the future benefit of marine as well as human communities.

INTRODUCTION

While oceans harbor approximately 80% of animal life on the planet, the Caribbean contains the greatest concentration of species in the Atlantic Ocean and is a global-scale hot spot for marine Biodiversity (Roberts *et al.*, 2002). The Caribbean Sea is a semi enclosed basin of the western Atlantic Ocean, with an

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area of about 2,754,000 km^2, bathed by currents that enter through the Lesser Antilles and the Windward Passage, and leave northwesterly towards the Gulf of Mexico to form the Gulf Stream. The most prominent marine ecosystems in the Caribbean are sea grass beds (66,000 km^2), coral reefs (26,000 km^2), and mangroves (11,560 km^2) (Miloslavich *et al*., 2010).

Coral reef and mangrove ecosystems are among the most productive and biodiverse tropical marine communities. Coral reefs harbor 4-5% of all known species and are responsible for the highest recorded oceanic productivities (1,500-5,000 gC·m^{-2}·year^{-1}). Mangroves forests line as much as 60-75 % of tropical coasts and may constitute 'biodiversity hotspots' themselves (Rützler *et al*., 2000), which have been demonstrated to increase reef fish productivity (Mumby *et al*., 2007). In recent decades, these ecosystems have suffered the consequences of uncontrolled human development (waste water pollution, habitat destruction, clear cutting, among others), and global warming. The area coverage of mangrove has decreased about 1% per year since 1980 (Agard *et al*., 2007), while live coral coverage has decreased 80% during the last two decades (Gardner *et al*., 2003; Wilkinson, 2004). Therefore, these ecosystems and the organisms within them are not in their prime conditions and must be studied to understand their role and function and preserved if we intend for the next human generations to continue benefitting from them.

Sponges may represent the most diverse benthic faunal component on Coral Reef and mangroves in the Caribbean (Figure 1). Reef sponges may reach four times the diversity of hard and soft corals (Diaz and Rützler, 2001), and mangrove sponges may equal or surpass the richest groups of macroalgae and ascidians, representing from 10 to 70% of the total root epiphytic diversity in various Caribbean sites (Diaz and Rützler, 2009). Marine sponges are essential to the ecology of these systems, mainly owing to their high capacity of water filtration and their role in metabolic processes, including those of their microbial associates (Diaz and Rützler, 2001; Lesser, 2006; de Goeij *et al*., 2008).

In 1972, the Smithsonian Institution's Caribbean Coral Reef Ecosystems Program (CCRE) established a field station on Carrie Bow Cay, a tiny sand islet off southern Belize formed by reef-crest debris, to provide year-round support for research by varied experts concerned with investigating biodiversity in the broadest sense, developmental biology, species interaction, oceanographic and carbonate-geological processes, community development over time, starting in the Pleistocene, and distributional, physiological, and chemical ecology. Early on, program participants consisted of staff of the National Museum of Natural History, but eventually, despite financial constraints, collaborators were brought in from other academic institutions worldwide. Numerous studies examined the biological and geological role of Porifera in the reef communities. At last count, 113 researchers focused on sponges of the Carrie Bow area, with 88 (78%) conducting fieldwork and the remainder coauthoring publications. Of the fieldworkers, 63 (72%) studied sponges directly, while the rest (25 or 28%) dealt with sponge associates. To date, 125 scientific papers have been published on the results of this research, while many more are in progress (Rützler, 2011). The present paper reviews our understanding of marine sponges in Belize and beyond to the greater Caribbean. We intend to reflect on the importance of these organisms to the marine communities they inhabit and to the human domain.

Material and Methods

We carried out a historical review of research in marine sponge biodiversity from Belize and the Caribbean from the early 1800s to the present using a comprehensive taxonomic list that contains classification and authorship information for all sponge species described for the Caribbean (Diaz, van Soest, Rützler and Guerra-Castro, in progress) The list can be found in the World Porifera database: http://www.marinespecies.org/porifera/ (Van Soest *et al*., 2010), or on the Porifera Tree of Life (PorToL) website (http://www.portol.org/resources).

We compiled our own data and published data from other authors and summarized information about the ecological role and pharmacological use of tropical marine sponges, updating our previous review (Diaz and Rützler, 2001).

Figure 1. Sponges are conspicuous components of coral reef and mangrove fauna. (Left) *Neofibularia nolitangere* (brown mounds) and *Callyspongia plicifera* (light bluish-gray tube) on a patch reef near Carrie Bow Cay, Belize. (Right). Three common mangrove species, *Mycale magniraphidiphera* (translucent), *M. microsigmatosa* (orange), and *Haliclona manglaris* (light green) covering red mangrove (*Rhizophora mangle*) rootlet tips in a tidal channel at Twin Cays.

RESULTS AND DISCUSSION

Porifera biodiversity in time

From the earliest descriptions by P.S. Pallas and J.B. Lamarck (mid-1700s and early 1800s) to the present, approximately 100 authors have contributed taxonomic descriptions of some 800 species of sponges from the greater Caribbean (Figure 2). The earliest comprehensive study of Caribbean sponges, published in 1864 by P. Duchassaing and G. Michelotti, dealt exclusively with collections from the Lesser Antilles, and included approximately 43 species. Subsequent work by J. S. Bowerbank, H. J. Carter, A. Dendy, O. Schmidt, and E. Topsent between 1858 and 1890 covered mainly the Gulf of Mexico and the West Indies, and added more than 150 species. The most prolific authors were the Austrian naturalist Oscar Schmidt, who contributed more than 165 species in 1870-80, and the North American Max Walker de Laubenfels who contributed more than 60 species during 1932-1954 (see Wiedenmayer, 1977 for literature review).

The first sponge known from Belize (then British Honduras) was a tiny (5x12 mm) *Polymastia biclavata* (now genus *Coelosphaera*), sent to England by a local collector and described by B.W. Priest before the Quekett Microscopical Club of London in 1881. This remained the only record from Belize for the next 56 years, until the British Rosaura Expedition of 1937/38 collected five species from Belize City harbor and Turneffe Island atoll; even those specimens were not described until M. Burton's treatise in 1954. When the participants of the CCRE program (Smithsonian Institution, National Museum of Natural History) arrived in Belize in the early 1970s, studies centered on systematics and faunistics, including the quantitative distribution of benthic organisms among the various shallow-water habitats (reachable with scuba diving). Over the next 30 years or so, taxonomy was approached by methods ranging from basic morphology to fine structure, DNA barcoding, and ecological manipulations. One highlight of these years was a workshop for six experts on Caribbean Porifera held at Carrie Bow Cay in 1997. CCRE studies have identified 30 new species, many as part of taxonomic revisions, local or Caribbean-wide, for instance of

the families Clionaidae, Mycalidae, Chalinidae and Axinellidae, and the genera *Lissodendoryx* (Coelosphaeridae) and *Iotrochota* (Iotrochotidae). Several species first described from Belizean mangroves were later found distributed on mangroves Caribbean wide.

Until now, 189 sponge species have been reported from Belize reef and mangrove habitats (Diaz *et al.*, in progress) This number represents only part of the diversity because many species that we collected remain unclassified and enigmatic and several prime sponge habitats remain unexplored for logistical reasons, such as the deep (below scuba) forereef, mesophotic bottoms, and cryptic environments. Experts estimate than once many regions, depths and habitats get explored, sponge biodiversity might nearly double, from the approximately 10,000 species recognized worldwide so far. The cumulative curve of number of species described per year in the greater Caribbean (Figure 2) shows that the sponge diversity in this region is still underestimated, and that whenever new geographic areas or different habitats are explored, undiscovered species are encountered. Such is the case of the recent description of thirteen new species from sciophilous habitats (cryptic areas of reefs, caverns, or small caves) from Curaçao and Colombia (Van Soest, 2009).

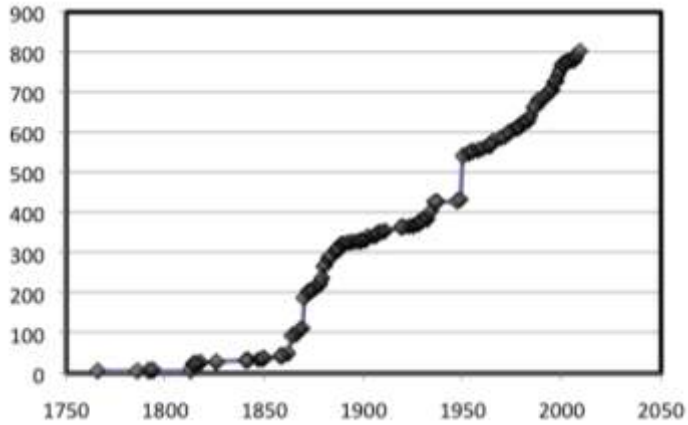

Figure 2. Cumulative number of sponge species described in the Caribbean from 1766 to the present.

Sponges are the most species-rich benthic animal group (165-265) in Cuba, Belize, and Jamaica, a higher diversity than elsewhere in the Caribbean (Miloslavich *et al.*, 2010). Belizean sponges (189 species) represent the third most diverse fauna in the greater Caribbean after Cuba (265 species) and South Florida with (228 species; Diaz *et al.*, in progress.). Comparing the diversities of five important marine animal groups (mollusk, crustaceans, echinoderms, corals and sponges) from 17 countries within various Caribbean marine ecoregions, Miroslavic *et al.* (2010) found that Belize ranked seventh in species richness. But, when they related species richness to the coastal area of each country, Belize ranked the fourth richest country, with 248 species/100 km, after Cayman islands (388 species/100 km), Costa Rica (362 species/100 km), and Puerto Rico (262 species/100 km).

Porifera in the Caribbean and habitat preservation

A classical approach to species conservation is to preserve the habitats where they live. This approach becomes even more critical when the species have specific habitat preferences. Scientists, park managers, or government officials might wonder how distinct mangrove and reef faunas are, and which habitat might be more important to protect. We have found that despite geographic contiguity between both habitats, their sponges present biological distinctness, which shows the importance of preserving both ecosystems. Diaz (in press) compared mangrove and coral reef sponge species composition in four distant Caribbean regions (Belize, Cuba, Panama, and Venezuela) and showed that the compositions of these faunas were statistically different. The taxonomic distinctness among faunas was observed at various supraspecific levels (genera, families). For example, major reef players such as species in the family Petrosiidae (genera *Xestospongia*, *Neopetrosia*, *Petrosia*), the family Agelasidae (*Agelas* spp.) and the order Verongida (*Aplysina*, *Verongula*), are basically absent from contiguous sponge-rich mangrove communities. On the other hand, the family Chalinidae (*Haliclona*, *Chalinula*) and the family Mycalidae (*Mycale* spp.) are more species-rich in mangroves than on coral reefs. It is assumed that differences might reflect distinct histories for both faunas. These results place in evidence the need to preserve both ecosystems in order to protect such distinctive faunal components.

Ecosystem services

Biological pumps

Vast volumes of water (up to 1 liter·cm^{-3} sponge tissue per hour) can be pumped and filtered by marine sponges (Reiswig, 1974). Estimating the biomass of sponge populations in three reef types in Belize, Wilkinson (1989) found the highest values (in wet weight) on inner (lagoon) reefs (1,011-2,458 g·m^{-2}), followed by barrier back reefs (99-1354 g·m^{-2}), and outer reefs (368-702 g·m^{-2}). Assuming an average daily pumping activity of 12 hours (Pile *et al.*, 1997), and a wet volume to weight ratio for sponge tissue of 0.5 (Corredor *et al.*, 1988), we can extrapolate that sponges in Belize reefs may pump 594-14,748 l water m^{-2}·day^{-1}. This large capacity of water filtration makes sponges not only filter feeders par excellence (Vacelet and Boury Esnault, 1995) but—owing to animal and microbial metabolic processes referred to below—gives these animals a unique role in water transformation with unprecedented ecological consequences. For example, sponges are well known to have high removal rates of particular organic carbon (POC; Reiswig, 1971; Richter *et al.*, 2001; Scheffers *et al.*, 2004) and even higher rates (up to two orders of magnitude) of removal of bulk dissolved organic carbon (DOC; Yahel *et al.*, 2003; de Goeij and van Duyl, 2007). De Goeij *et al.*, (2008) conclude that the three Caribbean thinly encrusting sponges *Halisarca caerulea*, *Merlia normani*, and *Mycale microsigmatosa*, are dissolved organic matter (DOM)-feeders and thus act as sinks of DOC on the reefs they inhabit.

The microbial processes of nitrification (aerobic transformation of ammonium to nitrite and nitrate) and denitrification (anaerobic reduction of nitrate to nitrogen gas) have been shown to occur among Caribbean and Mediterranean sponges, and project the highest benthic nitrification rates in tropical waters (Diaz and Ward, 1997; Southwell *et al.*, 2007; Schläppy *et al.*, 2010). Therefore, sponge population size and composition could strongly influence the concentration and speciation of dissolved inorganic nitrogen (DIN) in the reef and mangrove water column, affecting the new production in the ecosystems where they abound.

Other metabolic pathways must be evaluated to further predict the role of sponges in these marine systems.

Space competitors

Various encrusting sponges have been found to overgrow corals and other sessile invertebrates in the Caribbean (Vicente, 1978; Suchanek *et al.*, 1983; Aerts and van Soest, 1997). *Chondrilla nucula* (now, *C. caribensis*) has been the principal aggressor at least at three Caribbean sites: Puerto Rico (Vicente, 1978), St. Croix (Suchanek *et al.*, 1983), and Belize (Rützler, *et al.*, 2007). Two recently discovered thinly encrusting reef sponges, *Xestospongia bocatorensis* and *Haliclona walentinae*, both containing filamentous cyanobacteria as endosymbionts, were reported to overgrow even some highly aggressive species, fire coral (*Millepora* sp. and the toxic sponge *Neofibularia notilangere*; Diaz *et al.*, 2007). These species as well were shown to be phototrophs, acting like plants, sustaining photosynthetic rates much higher than their respiratory rates (Thacker *et al.*, 2007). Studies in the Colombian Caribbean identified the thickly encrusting *Desmapsamma anchorata* and the ramose species *Aplysina cauliformis* and *Callyspongia armigera* as the most frequent overgrowers (Aerts and van Soest, 1997). Morphological plasticity of sponges, their ability to attach to one another without causing harm (Rützler, 1970; Sarà, 1970), diverse chemistry (Faulkner, 2002), and microbial associations (Taylor *et al.*, 2007) are probably among the most important causes for their capacity to overgrow other organisms and avoid being overpowered by them.

Calcium carbonate cycle in the reefs

Sponges have a dual effect on reef frameworks: firstly, high levels of boring sponge activity may result in net decrease of reef accretion (Rützler, 2002) and, secondly, non-excavating demosponges are found to increase the rates of carbonate accretion by binding coral colonies, in both shallow and deep reef areas, reinforcing the reef frame and decreasing considerably the loss of coral colonies due to dislodgement by wave action, fish predation, and other forces (Wulff and Buss, 1979). Some burrowing clioanid species have become more abundant and have started to be considered as pests for Caribbean coral reefs (Williams and Bunkley-Williams, 2000).

Food and home for others

Spongivory is a common life style among several endangered turtle species and among coral reef fishes and seastars (Wulff, 1994; 2005). Hawksbill turtles (*Eretmochelys imbricata*) are known to feed mainly on a large variety of sponges in the Caribbean, and the green turtle (*Chelonia mydas*) includes among its varied diet several species of marine sponges. Besides being food for other organisms, sponges may harbor hundreds of animal and algal species during their lives (Villamizar and Laughlin, 1991).

Human services

Traditionally, some sponge species have been appreciated for their natural softness and resistance to tearing, and their ability to hold and discharge large amounts of water. Since the Roman times, they have been used to hold water or wine, to bath, of for medicinal uses. Nowadays, they are still used for cleaning cars or boats and for cosmetic purposes.

For the past 50 years, marine sponges have been considered a potential gold mine, owing to the diversity of their chemicals compounds called secondary metabolites (Sipkema *et al.*, 2005). They produce an enormous array of antitumor, antiviral, anti-inflammatory, immunosuppressive, antibiotic, and other bioactive molecules that can affect the pathogenesis of many human diseases. Sponges, in particular, are responsible for more than 5300 different chemical products, and every year hundreds of new compounds are being discovered (Faulkner, 2002), such as Ara-C, the first marine-derived anticancer agent, and the antiviral drug Ara-A (Proksch *et al.*, 2002). Ara-C is currently used in the routine treatment of patients with leukemia and lymphoma. Ara-A (Acyclovir) is an important antiviral agent. The marine biotech company Porifarma is developing sponge farms in western Turkey to supply sponge metabolites and act as biofilters for neighboring fish farms (de Goeij and Osinga, personal communication). Porifarma will farm two sponge species: *Dysidea avara*, which produces avarol that has antitumor, antibacterial, and antifungal properties, and *Chondrosia reniformis*, which is a good source of collagen that can be converted into nano-particles and used to deliver drugs to the target location (Duckworth, 2009). An important question for the future remains how to actually prepare the potential novel drugs on a large scale (Sipkema *et al.*, 2005). Belize's sponge biodiversity represents an unexplored 'treasure trunk' for metabolites with high pharmacological potential.

Last but not least, sponges, together with fishes, stony corals and soft corals are one of the most attractive members of the coral-reef community, thus having commercial importance for the diving industry. Their variety in shape, size, and intensity of colors, makes them stars in professional as well as amateur photography. One of the most attractive species in Caribbean coral reefs, the giant barrel sponges (*Xestospongia muta*), is considered the 'redwood' of the reef, for its size and presumed old age. McMurray *et al.* (2008) estimated that a sponge of 1 m diameter could be 100 years old, certain very large specimens as old as 2,300 years of age.

Threats to marine sponges

Caribbean sponges are under the same threats that menace their habitats. Among them are habitat destruction, sewage discharge, storm water run-off from polluted land, and global warming which has been increasing water temperatures and altering the ocean food chain and sea floor environment. Various diseases and mass mortalities have already been reported (Williams and Bunkley-Williams, 2000; Olsen *et al.*, 2006; Gochfeld *et al.*, 2007). In particular, although data are still scarce, these ancient animals should be sensitive to oil pollution as their survival depends on large volumes of water processed through their bodies. Zahn *et al.*, (1983) demostrate irreversible DNA damage of polycyclic aromatic hydrocarbon (PAH) through the binding of these oil derived compounds to macromolecular fractions in sponges.

The effect of large-scale oil spills, or long-term oil contamination has been recorded both from mangroves and coral reef ecosystems in the Caribbean. The largest oil spill in the Americas occurred in 1986 when more than 8 M liters of crude oil spilled into a complex region of mangroves, seagrasses, and coral reefs just east of the Caribbean entrance to the Panama Canal (Jackson *et al.*, 1989). Extensive mortality of shallow subtidal reef corals, mangrove communities, and infauna of seagrass beds were reported. After 1.5 years, only some organisms in areas exposed to the open sea had recovered. The results of chronic oil pollution from a refinery in Aruba (Netherlands Antilles), including spills and clean-up efforts are, after 60 years, still clearly discernible over a distance of 10 to 15 km along the reef, and includes deteriorated

reef structure, low living-coral cover, and fewer juveniles of reef organisms in front and down current of the refinery (Bak, 1987).

CONCLUSIONS

Sponges are one of the most diverse marine animals in coral reefs and mangroves of the Caribbean, representing an important structural and functional component of these ecosystems.

Belize, with respect to its marine habitat diversity and benthic marine fauna (echinoderms, mollusks, corals and sponges), is one of the richest countries in the Caribbean; therefore, its ecological integrity is important for the entire Caribbean ecosystem.

Estimates by experts indicate that probably at least 5000 sponge species worldwide remain to be discovered.

Sponges are the source for the highest benthic nitrification rates on the bottom of the oceans, the largest 'dissolved inorganic carbon sink' on Caribbean coral reefs, and the most diverse source of natural products from the ocean.

The protection of Belizean coral reefs and mangroves, and the waters that sustain them, is essential to the future existence of these important organisms and the potential of new discoveries and possible exploitation of their biomedical properties.

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BIODIVERSITY, ECOLOGY AND BIOGEOGRAPHY OF HYDROIDS (CNIDARIA: HYDROZOA) FROM BELIZE[1]

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ABSTRACT

An account of the species richness, assemblage composition, ecology and biogeography of the marine benthic hydroids (Cnidaria: Hydrozoa) across key marine habitats of Belize is provided. Patterns in species richness and composition stress the importance of local hydrography and seabed topography in controlling hydroid biodiversity across coral reef, mangal, seagrass and shallow wharf piling settings. The lack of knowledge regarding the biodiversity of hydroid species from deep-sea (>200 m water depth) settings in Belizean waters is striking, but species richness is expected to be very high given the large number of hydroid species identified from the deep-sea Caribbean in general. Hydroid species richness and composition are also closely governed by finer-scale features such as the diversity of suitable substrata, e.g., coral framework, seagrass thalli and other fauna (mainly sponges and molluscs), each of which differentially selects for species with adaptive morphologies and life history traits. The hydroid fauna of Belize show strong biogeographical affinities with that of the wider Caribbean, West Indies and the south-eastern US, demonstrating a significant influence of large-scale oceanographic features in structuring Belizean marine biodiversity.

INTRODUCTION

'Hydroids' are a group of benthic cnidarian invertebrates belonging to the Class Hydrozoa. Unlike other cnidarians, many hydrozoans alternate between sessile polyp and (sometimes almost entirely suppressed) medusa phases as part of their life histories including the Orders Limnomedusae, Anthoathecata, Leptothecata, but not the hydrozoan Orders Siphonophorae, Trachymedusae or Narcomedusae. The polyp phase is generally referred to as the hydroid phase, which may comprise a single individual polyp or a physiologically integrated colony of multiple and sometimes specialized polyps. While many hydroids are gelatinous, several anthoathecate families such as the Stylasteridae, Milleporidae, Hydractiniidae and Rosalindidae) possess calcified skeletons or basal encrusting mats.

Hydrozoans comprise mostly marine species, but some inhabit brackish and freshwater habitats. Over 3500 species have been identified, but molecular characterization of cryptic species is likely to reveal many more. They are typically hard substrate generalists, but species exhibit a range of life history strategies that differentially assembles species across space. Bacteria, algae, plants and other animals use hydroids themselves as hard substrata, and thus the occurrence and biodiversity of hydroids further enhances marine biodiversity. Hydroids are preyed upon by a variety of animals including sea turtles, fish, echinoderms, sea spiders, crustaceans and sea slugs. Hydroids themselves are generally suspension feeders, and actively feed in moderately strong water currents by capturing food with their polyp tentacles. Hydroids also paralyze living prey such as zooplankton by discharging stinging nematocyst cells from feeding tentacles. While hydroids are typically out competed for space by sponges, ascidians and octocorals, hydroid nematocysts are sometimes clustered into larger nematophores over the whole colony itself and offer an effective defense and offense strategy. However, the full tentacular and colony nematocyst complement is also often unfortunately and rather painfully discharged onto the exposed skin of divers, snorkelers and aquarists.

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The wider Caribbean region has the highest number of hydroid species in the Atlantic Ocean (Medel and López-González, 1998). Although the marine environments of Belize are some of the most species-rich in the Caribbean (Miloslavich *et al.*, 2010), study of the hydroid fauna has not been as intensive as it has been for that carried out for example on sponges or scleractinian corals. Regardless, targeted taxonomic investigation of hydroids in Belize consistently reveals new species or extends biogeographic ranges (e.g. Spracklin, 1982; Calder, 1988; Puce *et al.*, 2005). Existing information has been driven almost entirely by activities carried out directly by or in collaboration with the Smithsonian Institution. Data collection has been guided mostly by the long-running Caribbean Coral Reef Ecosystems Program from its field station site at Carrie Bow Cay and in mangrove habitats at Twin Cays and Wee Wee Caye. More recently, the Marine Invasions Research Lab at the Smithsonian Environmental Research Center has been monitoring Belize for non-native and exotic species introductions. Others have recorded hydroids incidentally as part of marine surveys conducted by the British Coral Cay Conservation at Turneffe Atoll, independently at Bacalar Chico (Ambergris Caye) and in lagoonal habitats at Snake Cays (southern Barrier Reef). Because about 50% of hydroids also produce a well-developed pelagic medusa as part of their life cycle, research into Belizean medusae must also be considered, however, this knowledge seems to be restricted to the medusa fauna from Carrie Bow Cay.

Materials and Methods

Herein, this research and the author's unpublished data are reviewed in their entirety to produce a contemporary species checklist of the hydroid fauna from Belize, inclusive of all Hydrozoa. These included Cairns (1982), Larson (1982), Spracklin (1982), Calder (1988, 1991), Ellison and Farnsworth (1992), Kaehler and Hughes (1992), Fenner (1999) and Puce *et al.* (2005).

Taxonomic revision required many published lists to be updated; for consistency, synonymies and taxonomy followed that of the World Registry of Marine Species (Appeltans *et al.*, 2011). Substrate and habitat affinities of Belizean hydroids are also reviewed to understand the role of environmental forcing across multiple spatial scales, including the importance of ocean circulation in creating the biogeographic affinities of hydroids from Belize in both shallow water and deep-sea (>200m) contexts.

Results and Discussions

A total of 117 hydrozoan species were identified from Belizean waters (Appendix 1), 103 of which were hydroids (i.e., those species producing a polyp phase as part of their life cycle). Of these 103 species, 30 were species records based solely from their medusa phase; thus the polyp phases of 73 hydroid species were listed. Excluding these 30 records of medusa phases to remove any taxonomic overlap, the unidentified corymorphid species from Spracklin (1982) as well as the *Amphinema* sp., *Leuckartiara* sp., and *Aequorea* sp. from Calder (1991a) can now be included. Thus, the polyp phases of 76 species of hydroid species have now been recorded from Belize (Table 1). Notably, none of these 76 species have been recorded in depths deeper than about 67 m (Spracklin, 1982). However, a large hydrocoral has been observed at nearly 300m depth off Glover's Reef (in Lutz and Ginsberg, 2007). The leptothecate *Kirchenpaueria halecioides* (Figure 1) is the most commonly encountered hydroid across all habitats in Belize.

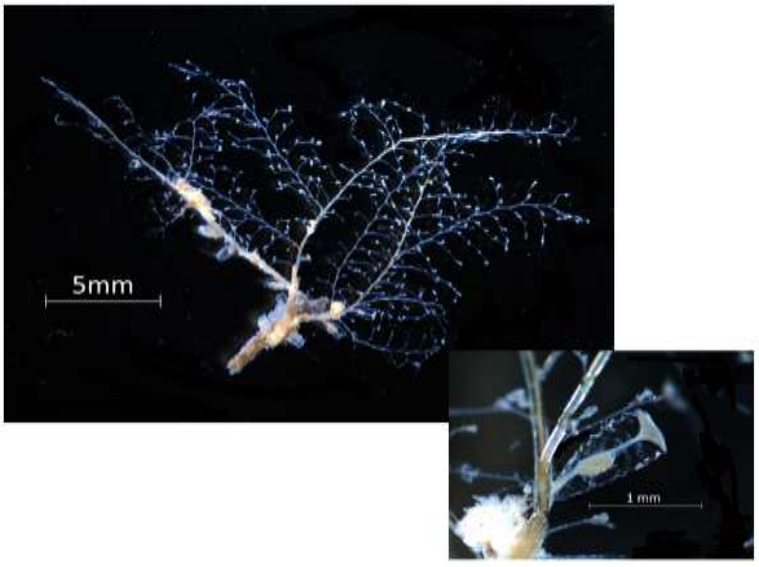

Figure 1. The most commonly encountered hydroid in Belize, *Kirchenpaueria halecioides*. Inset picture details the fixed sporosac gonophore of *K. halecioides* that contains its dispersive larval phase.

Table 1. Valid hydroid species of Belize and their common wider global distributions. Spracklin's (1982) unidentified species and other genera from Calder (1991a) are now included.

Species	Common distribution
Order Anthoathecata (29 species)	
Suborder Capitata	
Family Cladonematidae	
Eleutheria dichotoma De Quatrefages, 1842	North Atlantic, Mediterranean
Family Corymorphidae	
unidentified corymorphid sp. (in Spracklin, 1982)	
Family Corynidae	
Coryne sargassicola Calder, 1988	western North Atlantic
Family Halocordylidae	
Pennaria disticha (Goldfuss, 1820)	North Atlantic, Gulf of Mexico, Mediterranean, New Zealand, Red Sea, South Africa
Family Sphaerocorynidae	
Sphaerocoryne bedoti Pictet, 1893	North Atlantic, Mediterranean, Red Sea
Family Milleporidae	
Millepora alcicornis Linnaeus, 1758	Gulf of Mexico, Caribbean, Mozambique
Millepora complanata Lamarck, 1816	Gulf of Mexico, Caribbean
Millepora squarrosa Lamarck, 1816	Gulf of Mexico, Caribbean
Family Tubulariidae	
Ectopleura grandis Fraser, 1944	Gulf of Mexico
Zyzzyzus warreni Calder, 1988	tropical circumglobal
Family Zancleidae	
Zanclea alba (Meyen, 1834)	North Atlantic, Gulf of Mexico
Zanclea costata Gegenbaur, 1857	North Atlantic, Barents Sea, Mediterranean, Gulf of Mexico
Suborder Filifera	
Family Bougainvilliidae	
Bimeria vestita Wright, 1859	North Atlantic, Caribbean, Black Sea, South Africa, Indian and Pacific Oceans
Millardiana longitentaculata Wedler and Larson, 1986	tropical western Atlantic
Pachycordyle napolitana Weismann, 1883	North and central Atlantic, Mediterranean
Family Eudendriidae	
Eudendrium attenuatum Allman, 1877	Gulf of Mexico, sub-tropical northwest Atlantic
Eudendrium bermudense Calder, 1988	Bermuda
Eudendrium eximium Allman, 1877	Gulf of Mexico, sub-tropical north-western Atlantic
Eudendrium klausi Puce, Cerrano, Marques and Bavestrello, 2005	Belize
Myrionema amboinense Pictet, 1893	possibly North Atlantic, mostly west Pacific, Indo-Pacific, Indian Ocean
Myrionema hargitti (Congdon, 1906)	Gulf of Mexico, Caribbean
Family Hydractiniidae	
Hydractinia arge (Clarke, 1882)	northwest Atlantic
Family Oceaniidae	
Corydendrium parasiticum (Linnaeus, 1767)	North Atlantic, Gulf of Mexico, Caribbean, Mediterranean
Turritopsis fascicularis Fraser, 1943	Gulf of Mexico
Turritopsis nutricula McCrady, 1857;	North Atlantic, Gulf of Mexico, Caribbean
Turritopsoides brehmeri Calder, 1988	Belize
Family Pandeidae	
Amphinema sp. (in Calder, 1991)	
Leukartiara sp. (in Calder, 1991)	
Family Stylasteridae	
Stylaster roseus (Pallas, 1766)	Caribbean, Gulf of Mexico, northeast Brazil
Order Leptothecata (47) species	
Family Aequoreidae	
Aequorea sp. (in Calder, 1991)	
Family Campanulariidae	
Clytia hemisphaerica (Linnaeus, 1767)	circumglobal
Clytia latitheca Millard and Bouillon, 1973	South Africa, Red Sea
Clytia linearis (Thorneley, 1900)	Circumglobal, but not high Arctic or Southern Ocean
Clytia macrotheca (Perkins, 1908)	tropical western Atlantic, Gulf of Mexico
Clytia noliformis (McCrady, 1859)	Atlantic, Gulf of Mexico, Mediterranean
Clytia paulensis (Vanhöffen, 1910)	North Atlantic, Gulf of Mexico, Mediterranean
Clytia tottoni (Leloup, 1935)	eastern South Pacific
Obelia bidentata Clark, 1875	circumglobal
Obelia dichotoma (Linnaeus, 1758)	Atlantic and Pacific Oceans, Gulf of Mexico, Mediterranean, Red Sea, New Zealand
Orthopyxis sargassicola (Nutting, 1915)	western Atlantic, Brazil
Family Campanulinidae	
Egmundella grandis Fraser, 1941	Chesapeake Bay
Lafoeina tenuis Sars, 1874	North Atlantic, Gulf of Mexico, Arctic Ocean, Mediterranean, west Indian Ocean

Table 1. Continued

Species	Common distribution
Family Eirenidae	
Eutima sp. (in Calder, 1991)	
Family Haleciidae	
Halecium bermudense Congdon, 1907	Gulf of Mexico, western Atlantic
Halecium nanum Alder, 1859	Atlantic and Pacific Oceans
Halecium speciosum Nutting, 1901	eastern Pacific
Halecium tenellum Hincks, 1861	circumglobal
Hydrodendron mirabile (Hincks, 1866)	Atlantic Ocean, West Indies, Mediterranean, southwest Indian Ocean, New Zealand
Nemalecium lighti (Hargitt, 1924)	western Atlantic, Indo-Pacific
Family Hebellidae	
Hebella scandens (Bale, 1888)	North Atlantic, Gulf of Mexico, Mediterranean, South Africa
Hebella venusta (Allman, 1877)	Gulf of Mexico, Caribbean, Red Sea
Scandia mutabilis (Ritchie, 1907)	Gulf of Mexico
Family Phialellidae	
Phialella sp. (in Calder, 1991)	
Family Sertulariidae	
Diphasia tropica Nutting, 1904	Caribbean, tropical Atlantic
Dynamena crisioides Lamouroux, 1824	North Atlantic, Gulf of Mexico, South Africa, Mozambique, Red Sea
Dynamena disticha Bosc, 1802	North Atlantic, Gulf of Mexico, Mediterranean, Red Sea
Sertularella diaphana (Allman, 1885)	warm circumglobal
Sertularella peculiaris Leloup, 1974	South Atlantic, Lesser Antilles
Sertularia distans (Lamouroux, 1816)	North Atlantic, Mediterranean
Sertularia marginata (Kirchenpauer, 1864)	North Atlantic, Mediterranean, New Zealand
Sertularia tumida (Allman, 1877)	Gulf of Mexico
Sertularia turbinata (Lamouroux, 1816)	North Atlantic, Mediterranean, Caribbean
Symmetroscyphus intermedius (Congdon, 1907)	western North Atlantic, Caribbean
Thyroscyphus marginatus (Allman, 1877)	North Atlantic, Gulf of Mexico, Australia
Superfamily Plumularioidea	
Family Agalopheniidae	
Aglaophenia latecarinata Allman, 1877	North Atlantic, Gulf of Mexico, Red Sea
Aglaophenia pluma (Linnaeus, 1758)	North Atlantic, Mediterranean, South Africa
Family Halopterididae	
Antennella quadriaurita Ritchie, 1909	Atlantic, Gulf of Mexico, Indo-Pacific, New Zealand
Antennella secundaria (Gmelin, 1791)	North Atlantic, Gulf of Mexico, Mediterranean, Red Sea, New Zealand
Halopteris alternata (Nutting, 1900)	Atlantic, Caribbean, Gulf of Mexico
Halopteris carinata Allman, 1877	Atlantic, Caribbean, Gulf of Mexico
Halopteris diaphana (Heller, 1868)	North Atlantic, Mediterranean
Monostaechas quadridens (McCrady, 1859)	North Atlantic, Gulf of Mexico
Family Kirchenpaueriidae	
Kirchenpaueria halecioides (Alder, 1859)	North Atlantic, Caribbean, Mediterranean, Gulf of Mexico, Red Sea
Family Plumulariidae	
Plumularia margaretta (Nutting, 1900)	North Atlantic, Gulf of Mexico, Mediterranean
Plumularia setacea (Linnaeus, 1758)	North Atlantic, Gulf of Mexico, Mediterranean, Red Sea, South Africa
Plumularia strictocarpa Pictet, 1893	Gulf of Mexico, South Africa

Two species are endemic to Belize, *Turritopsoides brehmeri* (from mangal habitat, Twin Cays) and *Eudendrium klausi* (from coral reef habitat, Carrie Bow Cay). However, it is likely that with targeted taxonomic studies, there is no *a priori* reason to expect that these species are found exclusively in Belize. This is particularly true of *T. brehmeri*, which colonises both *Thalassia* seagrass and sponge substrata and is therefore likely to colonize other substrata outside mangroves (Calder, 1988).

Currently, the International Union for Conservation of Nature (IUCN) Red List of Threatened Species includes three hydroids found in Belize waters, all hydrocorals: *Millepora alcircornis*, *M. complanata* and *M. squarrosa* (since *M. striata* has been synonymized with *M. squarrosa*, the former species is provisionally not included here, but as of 2011 the IUCN still includes *M. striata* on its Red List). Only *M. squarrosa* is listed as decreasing in occurrence, but according to the IUCN, all three species remain categorized as being of 'least concern' in terms of becoming endangered or extinct.

Species diversity, composition and abundance of hydroids in Belize are all closely dependent on the occurrence, nature and variety of substrata. The richest species assemblages are found on dead or exposed tissue of scleractinians and gorgonian coral substrata including *Muriceopsis flavida*, *Pseudopterogorgia acerosa*, *P. bipinnata*, *Gorgonia flabellum* and *G. ventalina* (Spracklin, 1982; Puce *et al*., 2005). The seagrass *Thalassia testudinum* and algal substrata provided by *Halimeda* and *Sargassum* are also important in providing substrata for hydroids in Belize (Spracklin, 1982; Calder, 1988; Kaehler and Hughes, 1992), as are the sponges *Monanchora arbuscula*, *Cliona caribbaea*, *Tedania* (*Tedania*) *ignis*, (Spracklin, 1982; Calder, 1991a). Although the nature of the association is unclear, the hydrocorals *Millepora alcicornis* and *M. squarrosa* have been observed to encrust living corals as well (Fenner, 1999). Within mangrove habitats formed by *Rhizopora*, the most diverse assemblages are found on mangal prop roots (Calder, 1991b), particularly in areas with moderate to strong wave action or water currents (Calder, 1991a); this environmental setting helps prevent sedimentation and smothering of hydroids while delivering an adequate food supply.

While largely substrate generalists, certain species are better adapted to living on for example, ephemeral substrata such as *Thalassia* seagrass in Belize. Their morphologies, growth patterns and distribution on these substrata are selected for maximizing 'residence time' on seagrass leaves (Kaehler and Hughes, 1992), helping to ensure the hydroid survives to reproduce. Others, such as the hydrocorals *Millepora alcicornis* and *M. squarrosa*, can survive in spatially competitive environments like coral reef habitats by being able to rapidly encrust other corals. High risk of desiccation, competition, smothering and predation restrict the leptothecate hydroid *Dynamena crisioides* to a narrow depth range in Belize from the lower intertidal to the very shallow subtidal zone, where it exhibits significant intra- and interpopulation variation in morphology and reproduction to cope with environmental conditions (Calder, 1991c).

The biodiversity of the hydroid fauna also varies across wider habitat types. Based on the data to date, species richness and composition of the hydroid fauna varies between habitat categories (seagrass, man-made fouling plates, mangrove, patch reefs, back reefs, reef crest, spur and groove habitats, sand troughs, outer ridge, fore-reef slopes and floating *Sargassum*) (Figure 1). This review identified the highest number of hydroid species from mangroves (53 species), followed by patch reefs (21 species). Increasing proximity of mangroves to the barrier reef itself also enhances species richness of *Rhizopora* epibionts including hydroids (Ellison and Farnsworth, 1992), which may help to explain the high species richness of hydroid species seen at Twin Cays (Calder, 1991a). The relationship between mangal epifauna is also mutualistic: root epibionts help prevent boring by the root-boring isopod *Phycolimnoria* that reduces plant growth (Ellinson and Farnsworth, 1992). Given that so few studies have targeted the hydroid fauna in general, it remains to be seen whether mangroves truly support the richest assemblages. Notwithstanding lack of knowledge, it is clear that the habitat heterogeneity conferred by lagoonal habitats such as mangroves and patch reefs is of particular importance in sustaining high levels of hydroid biodiversity in Belize. Thus, the conservation of such habitats is vital in helping to sustain the marine biodiversity of Belize.

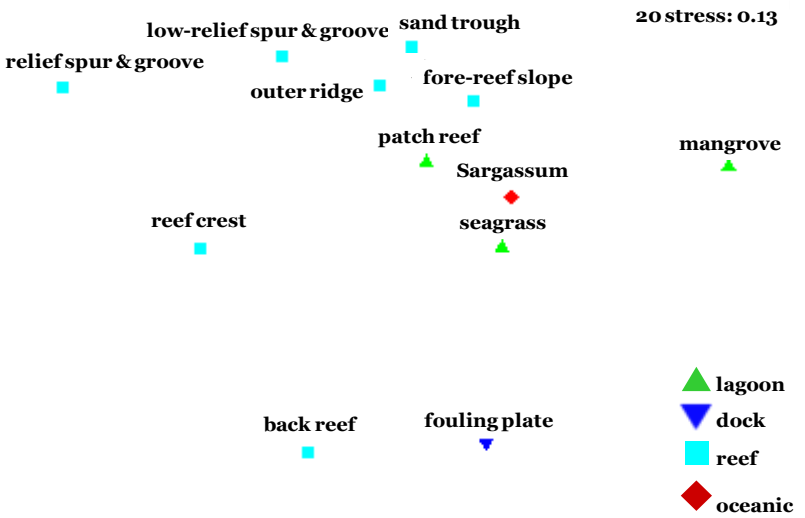

Figure 2. Non-metric multidimensional scaling plot of species Bray-Curtis dissimilarity indices based on presence/absence data (using PRIMER v6 software), comparing hydroid assemblages across wider habitat types (lagoonal, those collected on dock settlement plates, reef habitats and oceanic *Sargassum*). The overall low stress (0.13) indicates that hydroid assemblages are shaped differently across wider habitat niches.

Natural groupings of all habitat types occur according to whether they are artificial, lagoonal, reef or oceanic in nature (Figure 2), with lagoonal habitats exhibiting more consistent, i.e., more homogenous species composition than those from reef habitats where species composition varies more widely between

habitats (Figure 2). Thus, despite having the highest numbers of species or 'alpha' diversity, lagoonal habitats had lower species turnover, or 'beta' diversity. Hydroid biodiversity in Belize, therefore, depends both on forces driving high species richness in lagoonal habitats, and those that control high species turnover between coral reef habitats: thus, the total or 'gamma' diversity of hydroids in Belize will require the conservation of both habitat categories.

The general affinity of the hydroid fauna from Belize is West Atlantic Tropical (Briggs, 1974), comprised of widely distributed generally warm-water species also occurring in the Gulf of Mexico (see Calder and Cairns, 2009), across the North Atlantic and often the Mediterranean (Table 1). Surface water mass provenance in the Caribbean is temporally variable; the skeleton of corals from Belize and the wider Caribbean record decadal to annual fluctuations in the contributions of subtropical waters originating in the North Atlantic versus equatorial water masses originating from the South Atlantic (Druffel *et al.*, 1980; Kilbourne *et al.*, 2007). Caribbean inflow, via the Caribbean Current, flows northwest through the Caribbean Sea, tracking the bathymetry of the Nicaragua Rise and reaching Belize. Surface waters bathing the atolls of the southern margin including those at Turneffe Island and Glover's Reef are also connected to a deep-water corridor originating from the Honduras Bay Islands in the summer months (Tang *et al.*, 2006), and are strongly affected by mesoscale Caribbean Current eddies (Shcherbina *et al.*, 2008). The northward-moving Caribbean Current approaches the Yucatán Peninsula flowing through the Yucatán Straits to become the Yucatán Current moving into the Gulf of Mexico. This becomes part of the Loop Current, flowing through the Straits of Florida and becoming part of the Gulf Stream. The Gulf Stream circulates across the Atlantic, diverges eastwards at Cape Hatteras along the eastern US seaboard, eventually bringing warm saline waters to the western European margins as part of the North Atlantic Drift. Thus the biogeographic affinities of the hydroid fauna from Belize are driven by the large-scale surface and deep water circulation in the Caribbean, which effectively homogenizes the fauna across geographically distant areas. However, hydroid species richness remains higher at low tropical latitudes, where Belizean hydroid assemblages greatly resemble those from adjacent Caribbean regions, e.g., Puerto Rico, the Tortugas, Colombia and the Netherland Antilles (Calder, 1992).

Despite the striking absence of data on the Belizean hydroid fauna in waters greater than 200m, the strong West Atlantic Tropical affinity of this fauna makes it likely that these assemblages are reflected in the hydroids from the wider Caribbean region, which is the richest assemblage in the entire Atlantic (Medel and López-González, 1998). To date, 51 species of hydroids have been found in Caribbean waters >200 m water depth. In the greater western North Atlantic, deep-sea Caribbean hydroids have the closest affinity to those assemblages found nearby in the Straits of Florida and off the Bahamas, where 64 deep-sea hydroid species have been found (Henry *et al.*, 2008). It is therefore highly likely that many of these 51 species will comprise part of the Belizean deep-sea fauna, but this remains to be examined as such data are sparse throughout the entire Caribbean (Miloslavich *et al.*, 2010).

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APPENDIX 1: HYDROZOA OF BELIZE (INCLUSIVE OF ALL HYDROMEDUSAE) AND THEIR WIDER MORE COMMON GLOBAL DISTRIBUTIONS. VALID SPECIES (*). INVALID SPECIES ARE LISTED ACCORDING TO THE FAMILIES IN WHICH THEY CURRENTLY BELONG. ONLY THE MEDUSA OBSERVED IN BELIZE (M).

ORDER LIMNOMEDUSAE (polyps and medusa) 2 species
Family Olindiasidae
*M*Cubaia aphrodite* Mayer, 1894; tropical western Atlantic
*M*Olindias tenuis* (Fewkes, 1882); tropical western Atlantic

ORDER NARCOMEDUSAE (medusae only) 8 species
Family Aeginidae
*M*Aegina citrea* Eschscholtz, 1829; North Atlantic, Gulf of Mexico, Mediterranean, New Zealand, Indian Ocean
*M*Solmundella bitentaculata* (Quoy and Gaimard, 1833); North Atlantic, Gulf of Mexico, New Zealand, Indian Ocean

Family Cuninidae
*M*Cunina globosa* Eschscholtz, 1829; North Atlantic, Gulf of Mexico, Mediterranean, New Zealand
*M*Cunina octonaria* McCrady, 1857; North Atlantic, Gulf of Mexico, Mediterranean, Indian Ocean
*M*Cunina peregrina* Bigelow, 1909; Gulf of Mexico, eastern South Pacific, New Zealand, Indian Ocean

Family Solmarisidae
*M*Pegantha rubiginosa* (Kölliker, 1853); Atlantic and Pacific Oceans, Mediterranean
*M*Pegantha triloba* Haeckel, 1879; North Atlantic, Gulf of Mexico, Mediterranean, New Zealand
*M*Solmaris corona* (Keferstein and Ehlers, 1861); North Atlantic, Mediterranean

ORDER SIPHONOPHORAE (medusae only) 1 species
Family Physaliidae
*M*Physalia physalis* (Linnaeus, 1758); North Atlantic, Gulf of Mexico, Mediterranean, New Zealand

ORDER TRACHYMEDUSAE (medusae only) 5 species
Family Geryoniidae
*M*Liriope tetraphylla* (Chamisso and Eysenhardt, 1821); North Atlantic, Gulf of Mexico, Mediterranean, Indian Ocean

Family Rhopalonematidae
*M*Aglaura hemistoma* Péron and Le Sueur, 1810; North Atlantic, Gulf of Mexico, Mediterranean, Red Sea, New Zealand
*M*Amphogona apsteini* (Vanhöffen, 1902); central Indo-Pacific
*M*Persa incolorata* McCrady, 1857; North Atlantic, Gulf of Mexico, Mediterranean, New Zealand, Indian Ocean
*M*Rhopalonema velatum* Gegenbaur, 1857; North Atlantic, Gulf of Mexico, Mediterranean, New Zealand

ORDER ANTHOATHECATA (polyps and medusae) 53 species
Suborder Capitata
Family Cladonematidae
*M*Cladonema radiatum* Dujardin, 1843; North Atlantic, Gulf of Mexico, Mediterranean, New Zealand
**Eleutheria dichotoma* De Quatrefages, 1842; North Atlantic, Mediterranean
*M*Staurocladia vallentini* (Browne, 1902); Atlantic, Indo-Pacific, New Zealand

Family Corymorphidae
*M*Corymorpha forbesii* (Mayer, 1894); Atlantic, Mediterranean, New Zealand
*M*Corymorpha gracilis* (Brooks, 1822); Gulf of Mexico
M*Euphysora gracilis* (Brooks, 1882) (accepted as *Corymorpha gracilis* (Brooks, 1822)
M*Vannuccia forbesi* (in Larson, 1982, mis-spelled *Vannuccia forbesii* (Mayer, 1894), accepted as *Corymorpha forbesii* (Mayer, 1894)

Family Corynidae
*[M]*Cladosarsia capitata* Bouillon, 1978; western South Pacific
**Coryne sargassicola* Calder, 1988; western North Atlantic
[M]*Dipurena halterata* (Forbes, 1846) (accepted as *Slabberia halterata* Forbes, 1846)
[M]*Sarsia angulata* (Mayer, 1900) nomen dubium; tropical western Atlantic
*[M]*Slabberia halterata* Forbes, 1846; North Atlantic, Mediterranean

Family Halocordylidae
Halocordyle disticha (Goldfuss, 1820) (accepted as *Pennaria disticha* (Goldfuss, 1820))
**Pennaria disticha* (Goldfuss, 1820); North Atlantic, Gulf of Mexico, Mediterranean, New Zealand, Red Sea, South Africa

Family Milleporidae
**Millepora alcicornis* Linnaeus, 1758; Gulf of Mexico, Caribbean, Mozambique
**Millepora complanata* Lamarck, 1816; Gulf of Mexico, Caribbean
**Millepora squarrosa* Lamarck, 1816; Gulf of Mexico, Caribbean
Millepora striata Duchassaing and Michelin, 1864 (accepted as *Millepora squarrosa* Lamarck, 1816

Family Porpitidae
*[M]*Porpita porpita* (Linnaeus, 1758), probably inclusive of *Porpita linneana* nomen dubium Lesson, 1843; North Atlantic, Gulf of Mexico, Mediterranean, New Zealand

Family Sphaerocorynidae
**Sphaerocoryne bedoti* Pictet, 1893; North Atlantic, Mediterranean, Red Sea

Family Tubulariidae
**Ectopleura grandis* Fraser, 1944; Gulf of Mexico
**Zyzzyzus warreni* Calder, 1988; tropical circumglobal

Family Zancleidae
**Zanclea alba* (Meyen, 1834); North Atlantic, Gulf of Mexico
**Zanclea costata* Gegenbaur, 1857; North Atlantic, Barents Sea, Mediterranean, Gulf of Mexico
*[M]*Zanclea prolifera* Uchida and Sugiura, 1976; west North Pacific

Family Zancleopsidae
*[M]*Zancleopsis dichotoma* (Mayer, 1900); Gulf of Mexico, Atlantic

Suborder Filifera
Family Bougainvilliidae
**Bimeria vestita* Wright, 1859; North Atlantic, Caribbean, Black Sea, South Africa, Indian Ocean, Pacific Ocean
*[M]*Bougainvillia carolinensis* (McCrady, 1859); western North Atlantic, Gulf of Mexico
*[M]*Bougainvillia frondosa* Mayer, 1900; Gulf of Mexico, tropical west Atlantic
Garveia humilis (in Vervoort, 1968, accepted as *Bimeria vestita* Wright, 1859)
*[M]*Koellikerina elegans* (Mayer, 1900); Gulf of Mexico, Indian ocean
**Millardiana longitentaculata* Wedler and Larson, 1986; tropical western Atlantic
**Pachycordyle napolitana* Weismann, 1883; North and central Atlantic, Mediterranean

Family Cytaeididae
*[M]*Cytaeis tetrastyla* Eschscholtz, 1829; North Atlantic, Gulf of Mexico, New Zealand

Family Eudendriidae
**Eudendrium attenuatum* Allman, 1877; Gulf of Mexico, sub-tropical northwest Atlantic
**Eudendrium bermudense* Calder, 1988; Bermuda
**Eudendrium eximium* Allman, 1877; Gulf of Mexico, sub-tropical northwestern Atlantic
**Eudendrium klausi* Puce, Cerrano, Marques and Bavestrello, 2005; Belize
**Myrionema amboinense* Pictet, 1893; possibly North Atlantic, mostly west Pacific, Indo-Pacific, Indian Ocean
**Myrionema hargitti* (Congdon, 1906); Gulf of Mexico, Caribbean

Family Hydractiniidae
***Hydractinia arge* (Clarke, 1882); northwest Atlantic
**M*Hydractinia ocellata* (Agassiz and Mayer, 1902); western South Pacific
**M*Lizzia blondina* Forbes, 1848; Caribbean, northeast Atlantic, Mediterranean, New Zealand
*M*Podocoryne minuta* (in Larson, 1982, mis-spelled *Podocoryna minuta* (Mayer, 1900), accepted as *Lizzia blondina* Forbes, 1848)
*M*Podocoryne ocellata* (in Larson, 1982, mis-spelled *Podocoryna ocellata* (Agassiz and Mayer, 1902), accepted as *Hydractinia ocellata* (Agassiz and Mayer, 1902))
Stylactaria arge Clarke, 1882 (accepted as *Hydractinia arge* (Clarke, 1882)

Family Oceaniidae
***Corydendrium parasiticum* (Linnaeus, 1767); North Atlantic, Gulf of Mexico, Caribbean, Mediterranean
***Turritopsis fascicularis* Fraser, 1943; Gulf of Mexico
***Turritopsis nutricula* McCrady, 1857; North Atlantic, Gulf of Mexico, Caribbean
***Turritopsoides brehmeri* Calder, 1988; Belize

Family Pandeidae
**M*Amphinema rugosum* (Mayer, 1900); North Atlantic, Gulf of Mexico, Indian Ocean
**M*Amphinema turrida* (Mayer, 1900); North Atlantic, Gulf of Mexico, Mediterranean
**M*Larsonia pterophylla* (Haeckel, 1879); Caribbean, Gulf of Mexico, west Indian Ocean
***Leuckartiara* sp. (in Calder, 1991)
**M*Merga violacea* (Agassiz and Mayer, 1899); Gulf of Mexico, Mediterranean, western South Pacific
*M*Stomotoca pterophylla* Haeckel, 1879 (accepted as *Larsonia pterophylla* (Haeckel, 1879))

Family Proboscidactylidae
**M*Proboscidactyla ornata* (McCrady, 1859); North Atlantic, Gulf of Mexico

Family Stylasteridae
***Stylaster roseus* (Pallas, 1766); Caribbean, Gulf of Mexico

ORDER LEPTOTHECATA (polyps and medusae) 54 species
Family Aequoreidae
**M*Aequorea macrodactyla* (Brandt, 1835); Gulf of Mexico, eastern North Atlantic, central Pacific Ocean, New Zealand

Family Campanulariidae
***Clytia hemisphaerica* (Linnaeus, 1767); circumglobal
Clytia laxa Fraser, 1937 (accepted as *Clytia tottoni* (Leloup, 1935))
***Clytia latitheca* Millard and Bouillon, 1973; South Africa, Red Sea
***Clytia linearis* (Thorneley, 1900); circumglobal, but not high Arctic or Southern Ocean
***Clytia macrotheca* (Perkins, 1908); tropical western Atlantic, Gulf of Mexico
***Clytia noliformis* (McCrady, 1859); Atlantic, Gulf of Mexico, Mediterranean
***Clytia paulensis* (Vanhöffen, 1910); North Atlantic, Gulf of Mexico, Mediterranean
***Clytia tottoni* (Leloup, 1935); eastern South Pacific
***Obelia bidentata* Clark, 1875; circumglobal
***Obelia dichotoma* (Linnaeus, 1758); Atlantic and Pacific Oceans, Gulf of Mexico, Mediterranean, Red Sea, New Zealand
***Orthopyxis sargassicola* (Nutting, 1915); western Atlantic, Brazil

Family Campanulinidae
***Egmundella grandis* Fraser, 1941; Chesapeake Bay
Lafoeina amirantensis (Millard and Bouillon, 1973) (accepted as *Lafoeina tenuis* Sars, 1874)
***Lafoeina tenuis* Sars, 1874; North Atlantic, Gulf of Mexico, Arctic Ocean, Mediterranean, west Indian Ocean

Family Dipleurosomatidae
**M*Dipleurosoma collapsum* (Mayer, 1900); tropical west Atlantic

Family Eirenidae
*[M]*Eirene lactea* (Mayer, 1900); tropical west Atlantic
**Eutima* sp. (in Calder, 1991)
*[M]*Helgicirrha schulzei* Hartlaub, 1909; central to northeastern Atlantic, Mediterranean

Family Haleciidae
**Halecium bermudense* Congdon, 1907; Gulf of Mexico, western Atlantic
Halecium namum (in Spracklin, 1982, accepted as *Halecium nanum* Alder, 1859)
**Halecium nanum* Alder, 1859, Atlantic and Pacific Oceans
**Halecium speciosum* Nutting, 1901; eastern Pacific
**Halecium tenellum* Hincks, 1861; circumglobal
**Hydrodendron mirabile* (Hincks, 1866); Atlantic Ocean, West Indies, Mediterranean, southwest Indian Ocean, New Zealand
**Nemalecium lighti* (Hargitt, 1924); western Atlantic, Indo-Pacific
Ophiodissa mirabilis Stechow 1919 (accepted as *Hydrodendron mirabile* (Hincks, 1866))

Family Hebellidae
Hebella calcarata (Agassiz, 1862) (accepted as *Hebella scandens* (Bale, 1888))
**Hebella scandens* (Bale, 1888); North Atlantic, Gulf of Mexico, Mediterranean, South Africa
**Hebella venusta* (Allman, 1877); Gulf of Mexico, Caribbean, Red Sea
**Scandia mutabilis* (Ritchie, 1907); Gulf of Mexico

Family Laodiceidea
*[M]*Laodicea brevigona* Allwein, 1967; Gulf of Mexico, western North Atlantic

Family Lovenellidae
*[M]*Eucheilota paradoxica* Mayer, 1900; Caribbean, Gulf of Mexico, northeast Atlantic, Mediterranean, New Zealand

Family Malagazziidae
*[M]*Malagazzia carolinae* (Mayer, 1900); western North Atlantic, New Zealand
[M]*Phialucium carolinae* (Mayer, 1900) (accepted as *Malagazzia carolinae* (Mayer, 1900))

Family Phialellidae
**Phialella* sp. (in Calder, 1991)

Family Sertulariidae
Cnidoscyphus marginatus (Allman, 1877) (accepted as *Thyroscyphus marginatus* (Allman, 1877))
**Diphasia tropica* Nutting, 1904; Caribbean, tropical Atlantic
Dynamena cornicina McCrady, 1859 (accepted as *Dynamena disticha* Bosc, 1802))
**Dynamena crisioides* Lamouroux, 1824; North Atlantic, Gulf of Mexico, South Africa, Mozambique, Red Sea
**Dynamena disticha* Bosc, 1802; North Atlantic, Gulf of Mexico, Mediterranean, Red Sea
**Sertularella diaphana* (Allman, 1885); Caribbean, Gulf of Mexico, western Atlantic, Pacific Ocean, New Zealand, Indian Ocean
Sertularella parvula (Allman, 1888) in Spracklin, 1982, misidentified from *Symmetroscyphus intermedius* (Congdon, 1907)
**Sertularella peculiaris* Leloup, 1974; South Atlantic, Lesser Antilles
Sertularella speciosa Congdon, 1907 (accepted as *Sertularella diaphana* (Allman, 1885))
**Sertularia distans* (Lamouroux, 1816); North Atlantic, Mediterranean
**Sertularia marginata* (Kirchenpauer, 1864); North Atlantic, Mediterranean, New Zealand
Sertularia stookeyi Nutting, 1904 (accepted as *Sertularia distans* (Lamouroux, 1816))
**Sertularia tumida* (Allman, 1877); Gulf of Mexico
**Sertularia turbinata* (Lamouroux, 1816); North Atlantic, Mediterranean, Caribbean
**Symmetroscyphus intermedius* (Congdon, 1907); western North Atlantic, Caribbean
**Thyroscyphus marginatus* (Allman, 1877); North Atlantic, Gulf of Mexico, Australia
Tridentata distans (Lamouroux, 1816) accepted as *Sertularia distans* (Lamouroux, 1816))
Tridentata marginata (Kirchenpauer, 1864) (accepted as *Sertularia marginata* (Kirchenpauer, 1864)
Tridentata tumida (Allman, 1877) (accepted as *Sertularia tumida* (Allman, 1877))

Tridentata turbinata (Lamouroux, 1816); accepted as *Sertularia turbinata* (Lamouroux, 1816)

Family Tiaropsidae
*[M]*Tiaropsidium roseum* (Maas, 1905); central Indo-Pacific, New Zealand

Superfamily Plumularioidea
Family Agalopheniidae
**Aglaophenia latecarinata* Allman, 1877; North Atlantic, Gulf of Mexico, Red Sea
**Aglaophenia pluma* (Linnaeus, 1758); North Atlantic, Mediterranean, South Africa

Family Halopterididae
Antenella gracilis (in Spracklin, 1982, mis-spelled *Antennella gracilis* Allman, 1877, accepted as *Antennella secundaria* (Gmelin, 1791)
Antenella quadriaurita (in Spracklin, 1982, mis-spelled *Antennella quadriaurita* Ritchie, 1909)
**Antennella quadriaurita* Ritchie, 1909; Atlantic, Gulf of Mexico, Indo-Pacific, New Zealand
**Antennella secundaria* (Gmelin, 1791); North Atlantic, Gulf of Mexico, Mediterranean, Red Sea, New Zealand
**Halopteris alternata* (Nutting, 1900); Atlantic, Caribbean, Gulf of Mexico
**Halopteris carinata* Allman, 1877; Atlantic, Caribbean, Gulf of Mexico
**Halopteris diaphana* (Heller, 1868); North Atlantic, Mediterranean
**Monostaechas quadridens* (McCrady, 1859); North Atlantic, Gulf of Mexico

Family Kirchenpaueriidae
**Kirchenpaueria halecioides* (Alder, 1859); North Atlantic, Mediterranean, Gulf of Mexico, Red Sea
Plumularia haleciodes (in Spracklin, 1982, mis-spelled *Plumularia halecioides* Alder, 1859, accepted as *Kirchenpaueria halecioides* (Alder, 1859)

Family Plumulariidae
**Plumularia margaretta* (Nutting, 1900); North Atlantic, Gulf of Mexico, Mediterranean
**Plumularia setacea* (Linnaeus, 1758); North Atlantic, Gulf of Mexico, Mediterranean, Red Sea, South Africa
**Plumularia strictocarpa* Pictet, 1893; Gulf of Mexico, South Africa

DOCUMENTING THE MARINE BIODIVERSITY OF BELIZE THROUGH FISHBASE AND SEALIFEBASE[1]

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ABSTRACT

There is a large body of published material available on the marine biodiversity of Belize, including well over 1,000 scientific papers and other documents available online, notably through the Biodiversity and Environment Data System of Belize (BERDS). A large fraction of these publications were based on work done by the Smithsonian Institution in Belize, especially in Carrie Bow Cay. We briefly review the nature of these documents, which were used to enhance the contents of FishBase (www.fishbase.org) and SeaLifeBase (www.sealifebase.org) on fish and other metazoans, respectively. Jointly, these databases not only allow for a near complete inventory of the marine biodiversity of Belize (especially if completed by AlgaeBase; www.algaebase.org), but also will support detailed reviews and impact assessments, via the biological data that these databases make readily accessible.

INTRODUCTION

The Belize Barrier Reef, a UNESCO World Heritage Site, is the longest in the Atlantic (Gibson, this volume), comprising a major part of the world's second largest barrier reef, i.e., the Mesoamerican Reef (Cherrington *et al.*, 2010), which is one of the 43 marine priority ecoregions identified in Olson and Dinerstein (2002). Belize, which ranked 46th of 103 countries assessed for fish biodiversity by Baer (2001), is in the Western Caribbean (ranked 12th in terms of number of species and 9th in terms of endemism of 18 biodiversity hotspots worldwide; Roberts *et al.*, 2002; see also Myers *et al.*, 2000).

The region has been the object of marine biology studies, mainly by the continued efforts of the Smithsonian Institution for over 37 years (see Ruetzler, 2009). The various papers in this volume attest to the science and the wealth of knowledge that has been gathered on Belize marine biodiversity.

Meerman (2005) documented, through the Biodiversity and Environmental Resource Data System for Belize (BERDS; http://www.biodiversity.bz), 7,000 profiles of terrestrial and aquatic species, the best known being vertebrates and vascular plants. BERDS assembled this comprehensive account of Belizean biodiversity from several source databases, including FishBase as the source of all fish data (freshwater, brackish and marine). Meerman (2005) does not provide information on marine invertebrates. Miloslavich *et al.* (2010), though with a regional focus, provides some estimates of the number of species occurring in Belize for some groups of marine invertebrates. However, there is still not one authoritative list of the marine fauna of Belize, one of the important food and economic resource, if not the first, on which many Belizeans depend (see, e.g., Cisneros and Sumaila, Harper *et al.*, and Kirkwood and Matura-Shepherd, this volume).

This contribution aims to compliment the results of Meerman (2005), which mainly covers terrestrial organisms, with an improved coverage of marine life in Belize, from marine mammals to invertebrates, through FishBase and SeaLifeBase and with reference to AlgaeBase (www.algaebase.org) which provides a list of the algae found in Belize.

[1] Cite as: Palomares, M.L.D., Pauly, D., 2011. Documenting the marine biodiversity of Belize in FishBase and SeaLifeBase. *In*: Palomares, M.L.D., Pauly, D. (eds.), *Too Precious to Drill: the Marine Biodiversity of Belize*, pp. 78-106. Fisheries Centre Research Reports 19(6). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

Materials and Methods

The BERDS online version was consulted to obtain a preliminary list of the marine biodiversity of Belize as well as a preliminary bibliography of the scientific literature. This also gave us an idea of what the BERDS is missing in terms of large marine invertebrate groups, on which we can perform subsequent targeted searches. We then focused on large repositories of scientific literature notably that of the online archives of the Smithsonian Institution, the Biodiversity Heritage Library, the Aquatic Science and Fisheries Abstracts, Google Scholar and Web of Science, which we combed through using 'Belize' or 'British Honduras' and 'marine' as general keywords. We also made a general Google search for magazine, newspaper and blog articles that matched these keywords. Later, more targeted searches using the scientific names of taxa coupled with 'Belize' or 'British Honduras' were made, notably for the groups which were not particularly well covered by BERDS. Once these searches were exhausted, a regional search using keywords 'Caribbean' and 'Meso-America' were performed. All available literature was downloaded in PDF format, while literature for which electronic copies were not available were noted in a bibliographic Excel worksheet.

Taxonomic data for non-fish metazoans were checked against WoRMS (www.marinespecies.org) and the Catalogue of Life (CoL; www.catalogueoflife.org). Valid species names (i.e., names stamped by a WoRMS or CoL taxonomic editor) and their related synonyms were encoded in SeaLifeBase. Literature on fish species were submitted to the FishBase team, where the same taxonomic validation process was followed using the Catalog of Fishes. Species specific ecological and biological data were extracted after the valid species name has been cleared.

Results and Discussion

More than 1,000 references were found to match the search terms employed here, more than 600 of which contained the type of information that can be accommodated in FishBase and SeaLifeBase. Figure 1 summarizes the types of references used in this exercise, about half of which were published in peer-reviewed journals. This is probably an indication of their accessibility via the World Wide Web rather than of their relevance to the subject. Books, book chapters and reports accounted for about 40% of these references while the rest came from online databases and references (Figure 1). More than 400 references, not included in this analysis, but which are listed in the bibliographic list made available through the *Sea Around Us* home page (at www.seaaroundus.org, under 'Hot Topic', link to the ' Too Precious to Drill' conference website), contained more general information on geology, resource management and ecosystem functioning.

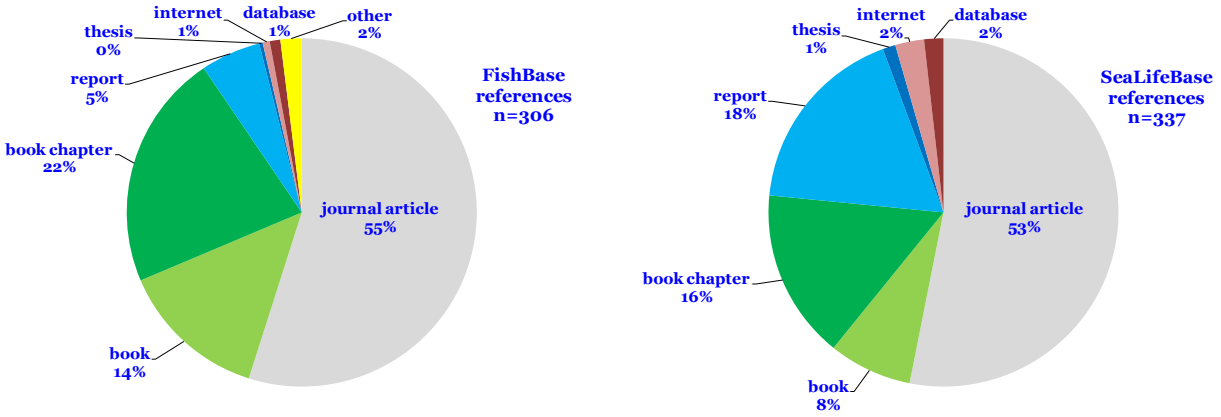

Figure 1. Types of references (total number=643) used in FishBase (A; for fish species) and in SeaLifeBase (B; for all other marine metazoans) for Belizean species (see detailed list in Appendices A and B, respectively). This does not include the more than 400 references which document geological, management and other policy issues in Belize, which are made available as a bibliographic list in the Conference website available through the *Sea Around Us* home page (see 'Hot Topic' at www.seaaroundus.org).

Four references used as 'Main Reference' for Belize in FishBase account for a third of the about 600 marine fish species currently available in FishBase, i.e., Claro (1994; 86 species), Acero (1985; 50 species), Greenfield and Thomerson (1997; 43 species), and Randall (1996; 36 species). Following these, are 13 references each of which document between 10-21 species representing over 28% and another 120 references each documenting between 1-9 species representing 38% of the Belizean fish species documented in FishBase. A detailed list of these references is included in Appendix A.

Three references used as 'Main Reference' for Belize in SeaLifeBase account for about half of the about 2,300 Belize non-fish species currently included in SeaLifeBase, i.e., Miloslavich *et al*. (2010; 667 species), Bright (2010; 206 species) and Guiry and Guiry (2009; 137 species). Following these are, *viz*.: 5 references documenting 40-70 species each which account for 12%, i.e., Hendler and Pawson (2000), Diaz and Ruetzler (2009), Rocha *et al*. (2005), Diaz and Erseus (1994) and Gischler and Ginsburg (1996); 33 references documenting between 10-38 species each, which make up 29%; and 117 references documenting between 1-9 species each, which make up the rest, i.e., 14% of Belizean non-fish species in SeaLifeBase. A detailed list of these references is included in Appendix B.

FishBase currently contains 552 bony fishes native to Belize (Pisces; Actinopterygii), 86% of which are found strictly in marine waters, 14% exist in marine and brackish waters, 9% are found in all aquatic environments (see Table 1), 1 is endemic and 1 exists only in brackish waters (see Table 2). FishBase has 28 species of Belizean sharks and rays (Pisces; Elasmobranchii), 13 occurring strictly in saltwater, 12 in marine and brackish waters and 3 in all aquatic environments (see Table 1). Meerman (2005) used the 2005 version of FishBase, which accounted for 669 marine and freshwater species of fish without identifying which ones are truly freshwater and truly marine species. In Table 1 we document, from the 2011 version of FishBase, 580 native and endemic fish species occurring in Belize marine waters, i.e., not including the truly freshwater species, after identifying and excluding misidentifications, erroneous and questionable species. Note that we cannot claim that this list is complete, notably since Chapman *et al*. (this volume) reports at least 18 species of sharks in Glover's Reef and Turneffe Atoll, and Lobel and Lobel (this volume) reports new species of gobies and wrasses waiting to be described. We can, however, claim that as of June 2011, FishBase contains the most authoritative list of fish species for Belize (go to www.fishbase.org, scroll down to 'Information by Country', choose Belize in the dropdown list, and click on the 'All Fishes' radio button).

SeaLifeBase, on the other hand, currently contains 2,272 species of native and endemic non-fish organisms from Belize, 86% of which are found strictly in marine waters, 12% in both marine and brackish waters, 5 are found in all aquatic environments, 1 in brackish waters only and 1 is endemic to Belize (see Table 2). The SeaLifeBase species counts presented in Table 1 compare fairly well with that of previous species counts for Amphipoda, Ascidiacea, Aves, Mammalia, Reptilia, Scleractinia, Echinodermata, and Mollusca. In addition, it is very close to those for Hydrozoa and Porifera. Again, we cannot claim that we have all of the marine organisms that can be found in Belize as we still have more than 400 references which we have not included in this analysis, i.e., because they deal with management issues, and the contributions in this volume, which may include a few species which have not yet been encoded, e.g., the deep-water corals in Henry (this volume). Note also the questionable species in Table 2, which though not included in the counts presented in Table 1, may become valid at some point in time. In the same manner as for fish species, recent sampling surveys may yet identify new species (see, e.g., the sea fan reported by Lobel and Lobel, this volume). However, we can claim that SeaLifeBase provides a first compendium of this kind for the marine non-fish metazoans of Belize comparable to that of BERDS for terrestrial organisms.

To get access to this list of species, go to www.sealifebase.org, scroll down to 'Information by Country', choose Belize in the dropdown list, and click on the 'All Species' radio button. The lists that the FishBase and SeaLifeBase web sites provide will include all species, i.e., native, endemic, introduced, questionable, error and misidentifications. Users are thus requested to carefully look at the list and to use only endemic and native species (and include with caution, introduced species) for checklist purposes.

This contribution demonstrated that published literature, if mined with care in a systematic and exhaustive manner, can lead to a preliminary authoritative list of marine and/or aquatic species in a country. We encourage experts on the marine biodiversity of Belize to validate the list that FishBase and SeaLifeBase has assembled. We also hope that this preliminary list will facilitate the efforts of the marine science and conservation community in Belize (and world wide) to build what is now a long overdue list of

marine flora and fauna of Belize, which can help, notably in efforts such as the 'Too Precious to Drill' campaign to inform Belizeans of what they stand to lose if oil drilling is permitted in their offshore and marine protected areas.

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Table 1. Number of native and endemic species occurring in Belize so far included in the July 2011 versions of FishBase (for Pisces) and SeaLifeBase (for all other groups) as compared with independent estimates by group. Phyla and Classes are here presented in alphabetical order (as opposed to phylogenetical order) documented using more than 600 references (see Figure 1). Note that though coverage of SeaLifeBase for certain groups, e.g., Scleractinia, appear sufficient, this list is not and will not be complete as the work on surveying and identifying, probably new and endemic species, continue (see, e.g., Lobel and Lobel, this volume).

Phylum	Class	marine	brackish	marine brackish	fresh, brackish marine	Total	Remarks
Annelida	Clitellata	50	–	1	–	51	
Annelida	Polychaeta	128	–	2	–	130	
Arthropoda	Malacostraca	190	1	14	1	206	24 species of Amphipoda in Miloslavich *et al.* (2010); SeaLifeBase documents 37 species of Amphipoda
Arthropoda	Maxillopoda	34	1	–	–	35	
Arthropoda	Ostracoda	3	–	–	–	3	
Arthropoda	Pycnogonida	33	–	–	–	33	
Bacillariophyta	Coscinodiscophyceae	1	–	–	–	1	
Bryozoa	Gymnolaemata	36	–	–	–	36	
Bryozoa	Stenolaemata	1	–	–	–	1	
Chlorophyta	Bryopsidophyceae	37	–	14	–	51	
Chlorophyta	Chlorophyceae	2	–	–	–	2	
Chlorophyta	Ulvophyceae	31	–	9	–	40	
Chordata	Amphibia	1	–	–	1	2	
Chordata	Ascidiacea	67	–	14	–	81	70 species in Goodbody (2000, cited in Gibson, this volume)
Chordata	Aves	33	–	–	–	33	21 historically occurring species in Jones and Balderamos (this volume); 37 in Paleczny (this volume)
Chordata	Mammalia	25	–	2	1	28	3 species of manatees in Auil-Gomez (this volume); 2 dolphins in Hines (this volume); 7 Cetacea and 1 Sirenia in Meerman (2005); SeaLifeBase documents 26 Cetacea, 2 Carnivora and 1 Sirenia
Chordata	Reptilia	4	1	4	1	10	7 species of Testudines, 2 Crocodilia and 111 Squamata (including terrestrials) in Meerman (2005); SeaLifeBase documents 4 sea turtles, 4 sea snakes and 2 crocodiles

Table 1. Continued.

Phylum	Class	marine	brackish	marine brackish	fresh, brackish marine	Total	Remarks
Ciliophora	Oligohymenophorea	–	–	1	–	1	
Cnidaria	Anthozoa	119	–	–	–	119	61 coral species in Fenner (1999, cited in Gibson, this volume); 51 Scleractinia in Miloslavich *et al.* (2010); 45 reef-building corals in Bright and Lang (2011, cited in Gibson, this volume); 6 cold-water species in Henry (this volume); SeaLifeBase documents 72 species of Scleractinia
Cnidaria	Cubozoa	1	–	–	–	1	
Cnidaria	Hydrozoa	32	1	70	–	103	117 Hydrozoa species in Henry (this volume)
Cnidaria	Scyphozoa	3	–	–	–	3	
Cyanobacteria	Not assigned	16	–	3	–	19	
Dinophyta	Dinophyceae	20	3	2	–	25	
Echinodermata	Asteroidea	19	–	–	–	19	134 species of Echinodermata in Miloslavich *et al.* (2010); SeaLifeBase documents 136 species (Asteroidea to Ophiuroidea)
Echinodermata	Crinoidea	5	–	–	–	5	
Echinodermata	Echinoidea	23	–	5	–	28	
Echinodermata	Holothuroidea	26	–	–	–	26	
Echinodermata	Ophiuroidea	58	–	–	–	58	
Foraminifera	Polythalamea	27	–	–	–	27	
Gnathostomulida	Not assigned	21	–	–	–	21	
Kinorhyncha	Not assigned	6	1	11	–	18	
Mollusca	Bivalvia	148	2	2	–	152	580 species of Mollusca in Miloslavich *et al.* (2010); SeaLifeBase documents 672 species (Bivalvia to Scaphopoda)
Mollusca	Cephalopoda	23	–	1	–	24	
Mollusca	Gastropoda	492	–	1	–	493	
Mollusca	Polyplacophora	1	–	–	–	1	
Mollusca	Scaphopoda	2	–	–	–	2	
Nemertea	Anopla	3	–	–	–	3	
Ochrophyta	Phaeophyceae	28	–	8	–	36	
Pisces	Actinopterygii	434	1	72	45	552	
Pisces	Elasmobranchii	13	–	12	3	28	18 species of Elasmobranchii in Chapman *et al.* (this volume)
Platyhelminthes	Trematoda	2	–	–	–	2	
Platyhelminthes	Turbellaria	1	–	–	–	1	
Porifera	Calcarea	3	–	1	–	4	193 species of Porifera in Miloslavich et al. (2010); 189 in Diaz and Ruetzler (this volume); SeaLifeBase documents 166 species (Calcarea and Demospongiae)
Porifera	Demospongiae	44	21	97	–	162	
Pteridophyta	Filicopsida	–	–	–	1	1	

Table 1. Continued.

Phylum	Class	marine	brackish	marine brackish	fresh, brackish marine	Total	Remarks
Rhodophyta	Florideophyceae	124	1	8	–	133	
Rhodophyta	Rhodellophyceae	1	–	–	–	1	
Sagenista	Bicosoecophyceae	–	–	1	–	1	
Sipuncula	Phascolosomatidea	10	–	–	–	10	
Sipuncula	Sipunculidea	3	–	1	–	4	
Tracheophyta	Equisetopsida	3	–	–	–	3	
Tracheophyta	Magnoliopsida	2	–	1	–	3	
Sipuncula	Phascolosomatidea	10	–	–	–	10	
Sipuncula	Sipunculidea	4	–	–	–	4	
Tracheophyta	Equisetopsida	3	–	–	–	3	
Tracheophyta	Magnoliopsida	3	–	–	–	3	
Total		**2409**	**33**	**354**	**53**	**2852**	

Table 2. Endemic marine and native brackish species (included in Table 1) so far documented as occurring in Belize. Questionable fish and other metazoan species also included in the July 2011 versions of FishBase and SeaLifeBase, respectively, but not included in the list presented in Table 1. This list is not complete, notably since new, probably endemic, species are currently being described (see Lobel and Lobel, this volume).

Phylum	Class	Order	Family	Genus	Species	Status
Chordata	Ascidiacea	Enterogona	Didemnidae	*Trididemnum*	*hians*	endemic marine
Pisces	Actinopterygii	Perciformes	Labridae	*Halichoeres*	*socialis*	endemic marine
Pisces	Actinopterygii	Siluriformes	Ariidae	*Cathorops*	*belizensis*	native brackish
Arthropoda	Pycnogonida	Pantopoda	Ammotheidae	*Ascorhynchus*	*serratus*	questionable marine
Mollusca	Gastropoda	Heterostropha	Omalogyridae	*Ammonicera*	*circumcirra*	questionable marine
Mollusca	Gastropoda	Neotaenioglossa	Rissoidae	*Alvania*	*moolenbeeki*	questionable marine
Pisces	Actinopterygii	Perciformes	Serranidae	*Alphestes*	*afer*	questionable marine
Pisces	Actinopterygii	Pleuronectiformes	Paralichthyidae	*Paralichthys*	*albigutta*	questionable marine
Pisces	Elasmobranchii	Torpediniformes	Narcinidae	*Narcine*	*brasiliensis*	questionable marine
Pisces	Actinopterygii	Perciformes	Serranidae	*Mycteroperca*	*microlepis*	questionable marine & brackish
Porifera	Demospongiae	Haplosclerida	Petrosiidae	*Neopetrosia*	*proxima*	questionable marine & brackish
Porifera	Demospongiae	Haplosclerida	Petrosiidae	*Neopetrosia*	*subtriangularis*	questionable marine & brackish

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APPENDICES

Appendix A. FishBase references used in assigning fish species to Belize. The numbers at the beginning of each line refer to the reference code used in FishBase.

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HABITATS

EVALUATING POTENTIAL IMPACTS OF OFFSHORE OIL DRILLING ON THE ECOSYSTEM SERVICES OF MANGROVES IN BELIZE[1]

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ABSTRACT

The environmental sciences play an important role in detecting, measuring, preventing, and mitigating the effects of pollution. Disturbances, non-linearities and complex interactions in ecosystems complicate predictions about pollution, but strong interactors and ecosystem engineers such as mangroves that form critical habitat necessary for the survival of other species allow decision makers to arrive at general predictions with reasonable certainty. This paper approaches potential impacts on the reef from the perspective of potential oil spill impacts on mangroves, the habitat they create, and their ecosystem services. Recent economic valuations show that Belizean mangroves annually contribute value approximately equivalent to 25% of the Belizean gross domestic product through the provision of nursery areas for fish and invertebrates, habitat for wildlife, and physical buffers against pollution, cyclonic storms and coastal erosion. The current condition of Belizean mangroves is reasonably good with less than 4% removal compared to a total global loss of 25%. Most mangrove loss in Belize results from real estate development and ecotourism, both of which are increasing. Oil exploration has had minimal effect on mangrove habitat to this point.

The potential for effects of oil on mangroves is high in the context of large exposures such as catastrophic oil spills. Effects of oil on mangrove differ from spill to spill, but normally include loss of associate and epiphytic organisms, loss of prop root structure, inhibition of germination, loss of genetic diversity, and mangrove death. Oil covering lenticels on prop roots or pneumatophores inhibits gas exchange and can suffocate adult trees. Toxins in oil also disrupt photosynthesis. Effects of spills vary, but mortality of mangroves after oil spills is common. Anaerobic mangrove soils tend to hold hydrocarbons for long periods, inhibiting recovery of attached organisms and repressing germination of new trees between 10 to 50 years. On wave-washed energetic shorelines such as those on cayes, lost mangrove is difficult, expensive, and sometimes impossible to replace. Nigeria, which has extensive mangrove habitat has lost much of the value of that ecosystem due to oil spills. Closer to Belize, an accident involving Venzuelan Mexican Isthumus Crude in Bahia Las Minas Panama during 1986 still shows effects on prop root density and associated mollusks 26 year later. Loss of resilience in mangrove populations could result in loss of valuable ecosystem services resulting in greater erosion, loss of nursery habitat, shorelines and biodiversity, directly affecting the economic security of Belize. These definitive risks must be balanced against short term economic gains from offshore oil extraction.

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THE DILEMMA OF PREDICTING EFFECTS OF DISTURBANCE ON COMPLEX ECOSYSTEMS

The complexity of nature presents a direct challenge to decision makers tasked with management of natural resources. Events in nature occur in open, complex ecosystems where contingent, often non-linear processes occur in a dynamic matrix of continually changing actors. Disturbances are ubiquitous and often entirely unexpected in nature and scope. Despite the advent of computers and the modern capacity to generate detailed individual-based or physical models, even small errors within such models are multiplicative and become large errors when projected over time. To date, no studies have described a complete predictive web of interactions in a large complex ecosystem like the Mesoamerican Reef including potential effects of energy flow, resource availability, behavioral plasticity and multi-scalar interactions between biotic and abiotic components of the system. It seems unlikely this will ever occur.

The modern scope and intensity of applied ecological problems creates a tension with this inability to precisely predict events in nature. Decision makers are often thrust into a world not so of grey, but of so much black and white thread coming from all directions that they experience a sort of tweed, where individual fibers of a system are so finely interwoven they cannot be easily teased apart. What will be lost if oil gets on the reef? If we lose species 'A' what will happen then to species 'B' through 'D'? In most cases, these questions cannot be answered until the full suite of direct and indirect effects of a disturbance actually occurs. Governments, nations, communities and individuals must make predictions about the results of their actions based on probability of risk based on incomplete perceptions of their ecosystems and the value they assign to each of the components therein.

Habitat-creating ecosystem engineers like mangroves and corals, exert sufficient control on the ecosystems, their fate provides some predictive power for the ecosystems they inhabit. The fate of strong interactors, ecosystem engineers and keystone species cascades directly onto the fate of many other organisms (Soulé *et al.*, 2003). Through their peculiar ability to survive in salt water as a woody plant and their resulting monolithic abundance, mangroves 'simplify' subtropical coastlines. Red mangroves (*Rhizophora mangle*) serve as nurseries for fish and invertebrates as well as habitat for wildlife associates and prop root assemblages. They prevent shoreline erosion and stabilize cayes. Because so many other species and ecosystem processes depend on mangroves for their own survival, knowledge of oil spill effects on mangroves becomes a potent predictor of at least some subsets of consequences for ecosystems. When mangroves are lost, significant portions of ecosystems are lost along with their ecosystem services.

The logic of simplifying communities in policy by focusing on a few key species is commonly used in agencies such as the United States Environmental Protection Agency. Numerical criteria for Total Maximum Daily Load (TMDL) regulations for contaminants in aquatic systems in the US are often created from knowledge of their effects on organisms important to society or which have very strong effects on ecosystems. Effects on ecologically and economically important west coast salmonids provide the bench mark to determine allowable contaminant loadings into western streams. Stream algae are responsible for fish kills and eutrophication in streams. TMDLs for nutrients that most strongly regulate the growth of algae are determined by loading rates most likely to prevent fish kills or anoxia. Although this approach does not account for all the effects of disturbances on ecosystems, by focusing on powerful actors in the ecosystem, some level of predictive capacity can be attained by assessing key taxa such as these. Further effects can then be assumed based on known relationship to other organisms and activity of the disturbance on other less easily approached assemblages and taxa.

BELIZEAN MANGROVES

Mangrove habitats provide a significant economic and environmental resource. Although only lightly exploited through direct uses such as firewood and lumber, ecosystem services provided by mangroves provide value equal to approximately 25% of the Belizean gross domestic product. This occurs by providing buffers for storms and coastal erosion, important nursery areas for fish and commercial species and venues for ecotourism (Cooper *et al.*, 2009). Developments that replace mangrove fringe with fill material where wave activity occurs are obliged to armor those shorelines immediately to prevent erosion losses. These hard engineering structures themselves are eventually undermined by wave activity and must be maintained and replaced. Sites where mangroves have been lost typically experience increased erosion, especially on high-energy shores. Tambo Caye near Corozal now exists as a mere strip of land a meter wide and a few meters across where it had once been a site for picnics. Mangroves on the Bluefield Range were cut and that caye range is now badly impaired, washed away by the waves.

Belizean mangroves also provide homes for endemic and economically important biodiversity. Juvenile snappers and other commercially important fish species use mangrove habitat during the day and forage out into seagrass meadows at night (Luo *et al.*, 2009). Goliath grouper depend on mangroves during early stages of their life history (Koenig *et al.*, 2007). Endemism on Belizean epibiota is discussed elsewhere in this text.

Belizean mangroves largely remain intact, despite global trends that have resulted in the loss of 25% of all coastal mangroves (Spalding *et al.*, 2010). Less than 4% of Belizean mangroves have been removed based on a thirty year analysis spanning 1980-2010 (Cherrington *et al.*, 2010). Low rates of mangrove removal may be due in part to laws banning their removal, but may also merely reflect the lack of opportunity to remove mangroves up to this point. Sites where population density is high have, by far, the highest rates of mangrove removal in the country.

Causes of Belizean mangrove removal, population density, real estate development, and tourism, are increasing (Cherrington *et al.*, 2010). Local populations have experienced substantial fragmentation and most local contractors reflexively remove mangroves and replace them with hard engineering structures such as seawalls when a property is sold for real estate development. Groups such as the World Wildlife Fund are working to reverse this trend and head off the kind of losses observed in other countries by promoting education, preservation and restoration efforts, and laws protecting mangroves in Belize are currently being strengthened.

Effects of Oil on Mangroves

To this point oil exploration and drilling have had a negligible effect on Belizean mangroves. However, experiences elsewhere indicate that significant losses could occur if a catastrophic spill were to occur. Mangroves themselves are fairly resilient to most heavy metal exposure and can withstand light exposures to hydrocarbons, although their epibiota often cannot. Individual organisms vary widely in their responses to oil sources, which are themselves highly variable in toxicity due to their own chemical constituents, age and temperature (Burns *et al.*, 1993, reviewed in Ellison *et al.*, 1999).

On mangroves themselves, heavy oiling that blocks gas exchange through lenticels on prop roots and pneumatophores will smother even adult trees (reviewed in Alongi 2002) and propagules (Grant *et al.*, 1993). Hydrocarbons absorbed during oil exposures also impede photosynthesis in mangroves (Youssef, 1993). Even recurrent light oiling can have a cumulative effect on mangroves in conditions of high salinity or other physiological stress (Burns *et al.*, 1993, reviewed in Ellison *et al.*, 1999) and in sites where repeated exposures to crude oil have occurred over time has resulted in mangrove mortality, (Garrity *et al.*, 1994), increased mutation rates in mangroves (Klekowski *et al.*, 1994) and reduced genetic variability of their microbial community, presumably as the result of selection for genotypes resistant to hydrocarbons (Taketani, 2009).

Oil spills close to home

In 1986, an oil storage tanker in Panama ruptured and spilled 50,000-100,000 barrels of Venezuelan Mexican Isthmus Crude oil into Bahia Las Minas, affecting 377 hectares of mangroves and killing 69 hectares of mangrove (Garrity *et al.*, 1994; Duke *et al.*, 1997; Levings *et al.*, 2002). Effects were concentrated on the mangrove fringe along tidal creeks and coastlines, the site most used by fish and the most diverse and economically important mangrove habitat for marine life. In affected areas, mangrove prop root density was reduced between 25 and 75% and a massive die-off in epifaunal communities occurred.

Studies in 2002 showed that mollusks living in Bahia Las Minas 16 years later were still contaminated with hydrocarbons released during tidal inundations. Bivalves brought into the area experienced high levels of mortality relative to local control specimens. Germination of mangrove propagules has also been inhibited and recovery has been slow (Levings *et al.*, 2002).

Due to the limited ability of anaerobic soils around mangroves to decompose crude oil, hydrocarbons absorbed there have remained in place to this day. Marsh soils in general shed hydrocarbon contaminants slowly with up to 25% of the original concentrations remaining underground at scales after 7 years (Michel 2009). Burrowing creatures such as crabs are typically found in lower densities in contaminated areas, and

do not burrow down to substrates with high concentrations of oil residues, thus reducing aeration and nutrient cycling in these habitats although the persistence of these effects are highly variable (Culbertson *et al.*, 2007; Melville *et al.*, 2009).

In Nigeria, frequent spills due to poor infrastructure and sabotage have reduced the function of mangroves and resulted in widespread disruption of communities that depend on their ecosystem services (Manby, 1999; Olujimi *et al.*, 2011). Estimates of total loss of mangrove are difficult to assess, but have been placed at between 5-10%. Much more mangrove habitat has become unusable and has lost its viability as an environmental resource.

Effects of spills tend to vary according to local circumstances. In some cases, effects of crude oil have been less pronounced. Roth and Baltz (2009) found recovery of fish and soils six months after an oil spill in a Louisiana salt marsh with little effect on fish. Diversity of algae may recover over a few months (Nwankwo, 2000). Other studies have found limited effects of repeated oiling on mangrove propagules (Proffit and Devlin, 1998). These studies were later criticized for low statistical power and unrealistic settings (Ellison *et al.*, 1999).

CONCLUSIONS

Although it will always be impossible to precisely predict all effects of oil spills in Belize with precision, the effects on mangrove ecosystems have been reasonably well studied and their general risks are well known. Observed results of spills in neighboring countries with similar ecologies indicate that the potential impacts of oil spills on Belizean mangroves are likely to be severe and will persist over decades where anaerobic soils experience heavy oiling. Effects on species such as mangrove that create habitat for whole assemblages of other organisms will inevitably harm fish and fishers who depend on mangroves as nursery habitat, epibiotic organisms that live on mangrove prop roots, ecotourism interests who depend on local biodiversity to attract business. Loss of adult mangrove forests and inhibition of new germination and thus re-growth could exacerbate shoreline erosion. The current value of mangrove services which represents a value of approximately 25% of the current Belizean gross domestic product will be at risk for decades in the case of a major spill. Taken in combination with other effects on other biota, an oil spill represents a significant additional threat among many existing threats to the Belize Barrier Reef System.

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BACALAR CHICO MARINE RESERVE: ECOLOGICAL STATUS OF BELIZE BARRIER REEF'S NORTHERNMOST RESERVE[1]

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ABSTRACT

Bacalar Chico Marine Reserve ('Bacalar Chico') is found on the northern section of Ambergris Caye, bordering Mexico. Established in 1996 as a Marine Protected Area (MPA), it is the only point along the Meso-American Barrier Reef System (MBRS) where two Marine Reserves, Bacalar Chico of Belize and Arrecife de Xcalak of Mexico, are connected to each other. The waters surrounding Bacalar Chico host a wide range of marine ecosystems, including coral reefs, seagrass beds, mangroves and sand cays and a diverse array of terrestrial wildlife. Generally the reefs of Bacalar Chico are similar to many degraded Caribbean reefs in their benthic, coral and fish composition, dominated by fleshy and turf algae and with low fish biomass and diversity. Despite the higher coral cover and coral and fish diversity in fisheries closures, the full benefit of management in attaining high biomass of key fish functional groups and diversity is not achieved yet and management effort should be intensified along with continued collection of baseline data to assess the effectiveness of the management of the marine reserve and monitor the health of the coral reef ecosystem. Considering the fragile nature of the coastal ecosystems and the existing high stress levels, any coastal development projects, including prospecting for minerals and oil that may further pose a threat to the ecosystems and well being of the communities should be critically assessed.

INTRODUCTION

Coral reefs of the Caribbean region have shown drastic declines in coral cover (by almost 80%), increased shift in benthic and coral community structure from coral to turf and fleshy algal dominance during the last few decades (Hughes, 1994; Szmant, 1997; Gardner *et al.*, 2003; Aronson and Precht, 2006). This shift occurred in conjunction with episodic events of coral disease and bleaching, but also overfishing and destructive fishing, excessive input of nutrients and other pollutants and coastal development (Gardner *et al.*, 2003; Aronson and Precht, 2006; Rogers and Miller, 2006; Schutte *et al.*, 2010).

This Caribbean wide decline in coral abundance is mostly associated with the white band disease outbreak of the late 1970s and successive bleaching events in 1982/83, 1987 and 1998 (Aronson and Precht, 2006; Schutte *et al.*, 2010). The 1998 event caused unprecedented damage to the Mesoamerican Barrier Reef System (MBRS), with a 19% reduction in Scleractinian coral cover (Kramer and Kramer, 2000). In October of the same year the category 5 Hurricane Mitch hit the region, causing significant damage and exacerbating the effects of bleaching (Kramer and Kramer, 2000), resulting in coral mortality of 50% or greater on some reefs (Garcia-Salgado *et al.,* 2008). The region has again seen record thermal stresses and bleaching in 2005 and 2010 (García-Salgado *et al.*, 2008; Eakin *et al.*, 2010). The decline in sea urchin biomass due to disease and herbivorous fish populations due to overfishing, and increase in nutrient input has shifted the balance in competition in favour of turf and fleshy algae resulting in a lower coral recovery and overall low reef resilience (Hughes, 1994; Bellwood *et al.*, 2004; Mumby *et al.*, 2006; Hoegh-Guldberg *et al.*, 2007).

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THE MESOAMERICAN BARRIER REEF

The Mesoamerican Barrier Reef System (MBRS) in the western Caribbean, stretches over 1000 km, and includes four countries, i.e., Mexico, Belize, Guatemala and Honduras. It is the second largest barrier reef in the world and the largest in the western hemisphere. The MBRS provides income to over one million people (Wilkinson *et al.*, 2008), primarily through tourism and fishing (Gorrez and McPherson, 2006). In 1996, the MBRS was declared a 'World Heritage Site' as it contains important and significant habitats for threatened species, areas of exceptional natural beauty and examples of unique ecological and biological processes.

The World Wildlife Fund (WWF) has identified the MBRS as a global priority for conservation. A collaborative effort between the four bordering countries resulted in the creation of the 'MBRS Synoptic Monitoring Program' which used standardised surveying methodologies and describes in detail the health of the coastal and marine ecosystems of the Mesoamerican region.

THE BELIZE BARRIER REEF

The core region of the MBRS is within Belize and is one of the world's biodiversity hotspots—recognised as one of the seven wonders of the underwater world (Conservation International, 2003). The area is of great conservational importance with endangered marine and terrestrial species, commercially important invertebrate species, turtle nesting colonies and fish spawning aggregations (Graham *et al.*, 2008). However, fish stocks are declining (Gibson *et al.*, 1998) and a large proportion of the coral reef is at risk of further large scale disturbances from coral bleaching and disease (Harvell *et al.*, 2007; García-Salgado *et al.*, 2008).

Efforts are being made to try to relieve the pressure on the coral reefs. A landmark ban on all trawling in Belizean waters went into effect on 31st December 2010. This is envisaged to limit the amount of habitat destruction and overexploitation of both target and non-target species. Fishing for conch and lobster is common throughout Belize and seasonal closures have been introduced to reduce their exploitation.

Considering its global significance for biodiversity conservation and the benefits to local communities, the collection of baseline data and establishment of long term monitoring programmes is of key importance to assess the health and sustainability of the coral reef ecosystem.

THE BACALAR CHICO MARINE RESERVE

Location and geography

Bacalar Chico Marine Reserve ('Bacalar Chico') is the most northern marine reserve found in Belize, where the coral reef runs parallel through the entire 300 km coastline. Bacalar Chico is found on the northern section of Ambergris Caye, bordering Mexico and spans 15,529 acres of coastal water. Established in 1996 as a Marine Protected Area (MPA), it is the only point along the MBRS where two marine reserves, Bacalar Chico of Belize and Arrecife de Xcalak of Mexico, are connected to each other. The waters surrounding Bacalar Chico host a diverse array of terrestrial and marine wildlife, as well as a wide range of marine ecosystems, including seagrass beds, mangroves, lagoons and sand cays.

The Bacalar Chico Marine Reserve is divided into four sections (Figure 1). The Preservation Zone (PZ) is found furthest north, adjacent to the Mexican border. It has the greatest restrictions in place as no fishing or water-based activities are allowed. The fore reef is separated by a wide, sandy channel which runs from Mexico down the length of the Preservation Zone, creating a double reef system. Either side of the valley are reef walls that extend upwards into rocky plateaus and reef flats. On the western side, reef flats extend from the reef crest into a steep wall leading into the valley. The eastern edge rises from the valley to form a rocky plateau, before sloping into deeper water forming spur and groove channels. The back reef consists of shallow patch reef and seagrass beds.

Conservation Zone 1 (CZ1) is adjacent to the Preservation Zone and while fishing is still banned, SCUBA diving is permitted under permission of the Fisheries Department. The reef is predominantly spur and groove with reef tops separated by narrow, deep sandy channels, which open up moving into deeper water. Some deeper patch reefs can be found in the back reef, as well as additional seagrass beds close to shore.

In Conservation Zone 2 (CZ2), only non-extractive activities are permitted, and sport fishing is regulated. It is a unique area as it contains the only point along MBRS where the reef meets the land (Rocky Point). There are fossil limestone remains of the coral reef that once thrived here when sea levels were higher. South of Rocky Point, at the end of Conservation Zone 2, the spur and groove formations continue into the area of highest coral cover in Bacalar Chico. The back reef up until Rocky Point consists of patch reefs with large sandy patches separated by large coral colonies.

The General Use Zone (GUZ), located either side of Conservation Zone 2, is the only area in the reserve where fishing is permitted. *Strombus gigas* (queen conch) and *Panularis argus* (spiny lobster) are the main target species, but line fishing and beach traps are also used. The lagoon is shallow, with an average depth of 2-3 m, whilst the fore reef continues with spur and groove reef formations until it runs into relatively barren reef flats.

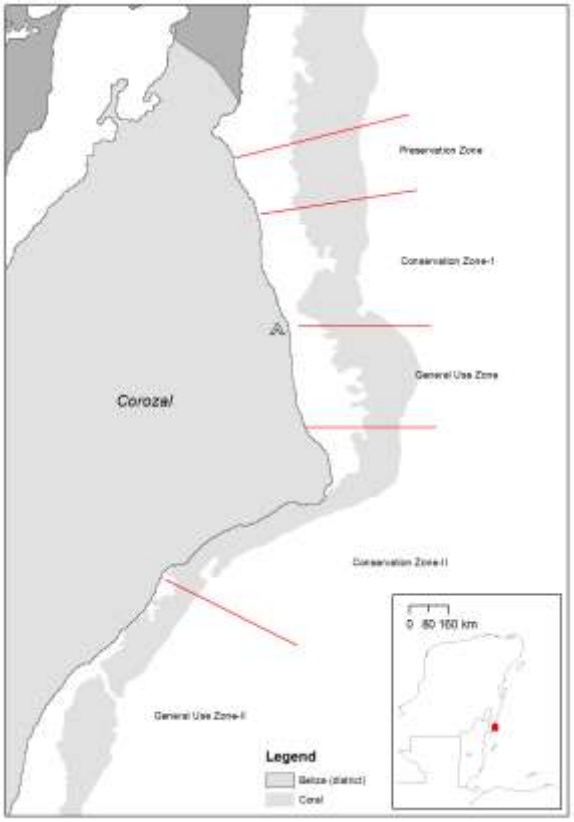

Figure 1. The four management zones of the Bacalar Chico marine reserve.

History and Context of Bacalar Chico Marine Reserve

Bacalar Chico is a marine protected area (MPA) and UNESCO World Heritage site that was set up in 1996 under the National Park Systems Act (Laws of Belize Chapter 215, Revised 2000) as a result of lobbying from local fishers from the village of Sarteneja. The marine reserve together with the National Park, the terrestrial area of Bacalar Chico, encompasses 60 km^2 and includes mangroves, lagoons, sublittoral forests and coral reef habitats.

The aims of establishing Bacalar Chico as an MPA were to ensure fish stocks remained sustainable, regulate water-based sports, prohibit illegal fishing and conduct monitoring and research. The reserve is managed by the Belize Fisheries Department, which has a ranger station on the western side of Ambergris Caye, facing the Corozal Bay Wildlife Sanctuary at San Juan. Despite Fisheries Officers being present year round, and conducting regular patrols, fishing incursions still occur. The fishers are predominantly from San Pedro on Southern Ambergris Caye and Xcalak, Mexico. At present the Bacalar Chico Fisheries Department carries out coral reef, mangrove, seagrass, bird nesting, turtle nesting, invertebrate and spawning aggregation monitoring.

Threats to the reef

Natural disturbances have had devastating effects on the coral reefs of Belize in the last three decades including hurricanes, bleaching events and disease epidemics (García-Salgado *et al.*, 2008). The increasing sea surface temperatures have resulted in an increase in both the number and severity of mass bleaching events (Aronson *et al.,* 2000).

Direct anthropogenic threats include overfishing, particularly that of key herbivorous fishes. The decline in these species has been linked to the observed large increases in macroalgae growth (Lewis and Wainwright, 1985; Lewis, 1986; Carpenter, 1990b). Increases in macroalgae coverage could have a severe impact on the coral reef as macroalgae compete with scleractinian corals directly for space and sunlight (Box and Mumby, 2007; Vu *et al.*, 2009). Therefore, herbivorous fish are vital in maintaining the health of the reef environment (Lewis, 1986; Carpenter, 1990a; Bellwood *et al.*, 2004; Bellwood *et al.*, 2006). In the absence of large biomass of herbivorous fish, mass mortality of *Diadema antillarum* urchins due to a

disease epidemic in the 1980's and 1990's throughout the Caribbean is thought also to have played a large role in increases in macroalgal biomass (Carpenter, 1990a; Lessios, 1995; Edmunds and Carpenter, 2001).

The increase in development along the Belize coastline is another major anthropogenic threat. Roberts *et al.* (2002) identified the Belize Barrier Reef as one of the reef systems most threatened by human impact. Recent studies have shown that over two-thirds of the coral reefs in the Caribbean are threatened by human activity (Burke and Maidens, 2004; Burke *et al.*, 2011). The removal of mangrove habitats is of particular concern, as they are vital to the success of coral reef ecosystems; they provide vital habitat for juvenile reef fish, filter run-off from the land and prevent erosion of the land (Ronnback, 1999; Mumby *et al.*, 2004; Harborne *et al.*, 2006). At present, there is very limited development in Bacalar Chico, with the closest settlement in the north, the village of Xcalak in Mexico, which is outside the reserve, and the nearest settlement is approximately 25 km south, the Tranquillity Bay Hotel. However, with much of the coastline privately owned land, an increasing number of hotel complexes have been built in the southern part of the reserve and land has been cleared for development. Therefore coastal development seems likely to become a greater threat to Bacalar Chico.

Previous assessment of Bacalar Chico Marine Reserve

The Bacalar Chico Marine Reserve management plan was prepared in 1995 (Dotherow *et al.*, 1995), making it amongst the first of seven Marine Reserves to come under the direct management of the Belizean Fisheries Department.

The MBRS Synoptic Monitoring Programme identified areas for monitoring in Mexico, Belize, Honduras and Guatemala (Garcia-Salgado *et al.*, 2008). Eight MPAs in Belize were selected for monitoring, including the Bacalar Chico Marine Reserve. Within Bacalar Chico, five sites were chosen for monitoring purposes. During baseline surveys of the selected MPAs in 2004, Bacalar Chico was found to have the largest populations of herbivorous fish species (Acanthuridae and Scaridae; García-Salgado *et al.*, 2008.). However, overall fish abundance dropped from an average of about 40·100 m² in 2004-2006 to below 22·100 m² in 2007 (García-Salgado *et al.*, 2008). Initial analysis of the 2004 data indicated that Bacalar Chico was in 'alert status' with less than 19% of Scleractinian coral cover, though by 2008 it was reported to be in good condition as the data showed that hard coral cover had increased by 15% (18% in 2004 to 33% in 2008; García-Salgado *et al.*, 2008).

THE 2010 ASSESSMENT

In 2010, Blue Ventures Conservation initiated a coral reef monitoring programme in Bacalar Chico. Benthic and coral community composition and reef health, fish abundance and biomass, density and sighting frequency of invasive, commercially important and endangered fish species and megafauna were surveyed using the MBRS Network survey model (Almada-Villela *et al.*, 2003).

The majority of sites surveyed had low scleractinian coral cover (average cover 10.5%), high cover of turf and fleshy algae. *Dictyota* and *Lobophora* were the fleshy macroalgal species with high abundance form dense mats which prevent coral settlement. This low coral cover is typical of the Caribbean and MBRS that have seen a dramatic decline in coral cover over the last few decades (Gardner *et al.,* 2003). Associated with the decline in herbivorous fish and sea urchin biomass and increase in nutrient levels, sedimentation, hurricane activity and coastal development, overtime, the reefs have become less resilient (Lessios *et al.*, 1984; Hughes, 1994; Edmunds and Carpenter, 2001; Gardner *et al.*, 2005; Vargas-Ángel *et al.*, 2007; Wilkinson *et al.*, 2008). The healthiest reef sites were found on the fore reef in PZ and CZ2, where high coral cover (>20%) and species richness and diversity were observed. These 2 zones are also two of the few places to have relatively high abundances of the IUCN 'critically endangered' coral species, *Acropora palmata* (PZ) and *Acropora cervicornis* (CZ2). The coral community composition reflects the disturbance history of the region and the influence of the hydrological systems in the study area. The most abundant coral species belong to species with opportunistic life history strategy with encrusting growth form, e.g., *Porites astreoides* and *Agaricia agaricites*.

Total abundance and abundance of major fish families and species diversity were higher on the fore reef and fringing reef than the back reef and on the conservation/preservation zones than the general use zone. Haemulids were an exception, having highest abundance on the GUZ. Patterns in total fish biomass and biomass of economically and commercially important fish species was less clear, as there were high and low biomass sites within the different reef habitats and conservation zones. Sites with highest coral cover

did not have a particularly high abundance or biomass of key fish functional groups. They tend to have specific topographical features which influence abundance rather than the health of the reef itself. In many cases, large biomass values were due to the large haemulid biomass in specific areas as reported by Hawkins and Roberts (2004). The mismatch in the patterns between total fish abundance and biomass is probably caused by the difference in fish size. Sites with low fish abundance could have large biomasses due to the presence of a few, but large individuals.

Large spawning aggregations were observed in Bacalar Chico off Rocky Point, where large abundances of Serranidae, Lutjanidae and Carangidae species can be seen leading up to the full moon. The specific geomorphology of the reef with a gently sloping contour and the environmental conditions with variable currents provide ideal habitat for spawning aggregations (Heyman and Kjerfve, 2008). Spawning probably occurs throughout the year, with different species forming spawning during a particular season of a year as observed southern in Belize (Heyman and Kjerfve, 2008). Thus, any fishing targeting this area is expected to have significant effects on the fish populations involved. Shark species were less frequently encountered, with *Ginglymostoma cirratum* (nurse shark) having the highest number of sightings. A single sighting of *Rhincodon typus* (whale shark) was recorded on 8th May 2010. Ray fish abundance was relatively high, with 144 *Dasyatis americana* (southern stingray) and 37 *Aetobatus narinari* (spotted eagle ray) individuals sighted. The majority of *D. americana* and *A. narinari* were sighted on the back reef, with a few, but larger individuals seen on the fore reef.

Four species of marine turtles were seen, the most frequently encountered was *Eretmochelys imbricata* (hawksbill sea turtle) with 36 sightings over 6 months. *Caretta caretta* (loggerhead sea turtle) was encountered 14 times, with most sightings around the breeding season in May and June. *Chelonia mydas* (green sea turtle) was less frequently encountered. There was also one sighting of *Dermochelys coriacea* (leatherback sea turtle).

Two species of dolphins were encountered, *Stenella frontalis* (Atlantic spotted dolphin) and *Tursiops truncatus* (bottlenose dolphin). From October to November, large pods of *T. truncatus* were commonly encountered both on the fore reef and the back reef. The *Trichecus manatus* (manatee) population in Bacalar Chico appeared to be relatively small, with 15 sightings in both the mangroves and the back reef. Sightings in the mangroves were most common from March to May, with subsequent sightings only on the back reef when animals were observed feeding in seagrass beds.

A major problem faced on the Mesoamerican Barrier Reef is the growing threat of invasive species, primarily *Pterois volitans* (lionfish), which feeds voraciously on recruits and juveniles of reef fishes and has no evident predators in the Caribbean. An increasing number of invasive lionfish, *Pterois miles* and *Pterois volitans,* have been found in Belize including Bacalar Chico. In March 2010, lionfish sightings in Bacalar Chico were considered rare. There were 78 sightings between 10th September and 5th October 2010 and 109 between 29th October and 22nd November 2010. The vast majority of sightings were on the fore reef and at depths below 10 m. Most sightings were in areas where there were large numbers of recruits and juvenile fish, the prime prey of lionfish. The increase in lionfish sightings during the study period is in agreement with other observations in other areas of the Caribbean (Schofield, 2009) with expected negative effects on indigenous fish populations and reef ecology in general (Albins and Hixon, 2008).

CONCLUSIONS

Patterns in benthic and coral composition, fish abundance, biomass and diversity, on the coral reefs of Bacalar Chico are typical of degraded Caribbean reefs dominated by fleshy and turf algae. Considering the age of the marine reserve, full benefit of management has not been achieved yet. The absence of particularly high biomass of key fish families in the conservation zones suggests that management is not strongly enforced. Continued collection of baseline data should be ensured in order to assess the effectiveness of the management of the marine reserve and monitoring reef health of the coral reef ecosystem. Any coastal development projects in this already stressed ecosystem should be critically assessed so that they don't interfere with the long-term management of the marine resources.

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PREPARING FOR POTENTIAL IMPACTS OF OFFSHORE PETROLEUM EXPLORATION AND DEVELOPMENT ON THE MARINE COMMUNITIES IN THE BELIZE BARRIER REEF AND LAGOONAL ECOSYSTEMS[1]

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ABSTRACT

It seems inevitable that Belize and especially its offshore areas will be the focus of a major exploration effort within the next few decades. Oil companies hungry for new reserves are actively searching for new little-explored areas like Belize. Limited drilling has so far found no major discovery, but several shows of oil are encouraging. Some of the same age carbonate rocks that are so productive in Mexico also underlie Belize. The open shoreline can provide harbors and ocean access to world markets. The probability of expanded exploration in Belize mandates that now is the time for the Government to establish an independent petroleum commission. The first assignment of this Commission could be to prepare a comprehensive report on past impacts in tropical areas of exploration and production, especially those with coral reefs (Panama, Indonesia, Persian Gulf). In addition, the report should include an inventory of the natural resources of Belize (coral reefs, beaches, fisheries, mangroves), maps showing the extent of each, and estimates of their total contribution to the economy. The review of past impacts will identify those most likely to impact Belize. The inventory of natural resources will identify the most valuable ones. Together this combination provides the necessary background for strategic risk management as well as key information to prepare regulations of exploration and production activities.

[1] This Abstract was submitted by Dr. R. Ginsburg before he underwent hip surgery in June 2011, optimistically foreseeing a quick recovery. Unfortunately, he was not able to participate in this conference. We keep it here so that readers are aware of Dr. Ginsburg's contributions to Belizean marine biology.

A DEEP-SEA CORAL 'GATEWAY' IN THE NORTHWESTERN CARIBBEAN[1]

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ABSTRACT

'Cold-water' corals are an artificial group of taxa comprising scleractinians, some zoanthids, antipatharian black corals, octocorals and some hydrozoans. While we are familiar with shallow warm-water corals and coral reef ecosystems, most people are not aware that cold-water corals are globally distributed in all Earth's oceans, with 65% of their species occurring in waters >50 m depth. In the northwest Caribbean region, 46 species of scleractinians have been identified from the deep-sea (>200m), including the large colonial species *Madrepora oculata* Linnaeus, 1758 and the reef framework-constructing *Lophelia pertusa* (Linnaeus, 1758). As an ecosystem engineer, *L. pertusa* modifies the physical and biological features of its local environment and promotes the colonization of thousands of invertebrate and fish species, which greatly enhances overall deep-sea biodiversity. Recent sediment profiling and multibeam surveys in the region identified mounded features in the Yucatán Straits that were possibly constructed by *L. pertusa*, but more often in this region, *L. pertusa* occurs on hard grounds, sitting atop erosional unconformities. Despite the lack of public-accessible deep-sea habitat mapping initiatives in the offshore region of the Belizean exclusive economic zone (EEZ), the occurrence of *L. pertusa* close by off Roatán in the Honduras at over 400m water depth and the possibility of cold-water coral mound build-up in the Yucatán warrants further investigation in the Belizean EEZ. This is especially true given the known consequences of oil exploration and drilling activities/accidents on *L. pertusa*, and particularly since the northwest Caribbean could act as a key 'gateway' for cold-water coral ecosystems between the Brazilian continental shelf and those in the Florida Straits and Gulf Stream and beyond.

COLD-WATER CORALS

Deep-water corals are an artificial group of coral species including scleractinians, zoanthids of the genus *Gerardia*, antipatharian 'black corals', octocorals, and stylasterid 'hydrocorals' occurring at depths exceeding 200 m. Although zooxanthellate scleractinian corals from warm shallow waters are most familiar to us, knowledge of the deep 'cold-water' coral fauna has exponentially increased over the last decade (Roberts *et al.*, 2009). Species richness of these deep, cold-water corals is becoming increasingly evident, with for example, 87% of azooxanthellate scleractinians occurring in depths greater than 50 m and occurring in all Earth's oceans (S. Cairns, in Roberts *et al.*, 2009).

Many of these cold-water coral species are constructional, in that they contribute to reef-framework structures, or are in some way habitat-forming species (Cairns, in Roberts *et al.*, 2009). As large, biogenic and positive topographic features reaching hundreds of meters high and several kilometers long, cold-water corals enhance biodiversity by greatly increasing habitat heterogeneity available for species to colonize (Buhl-Mortensen *et al.*, 2010). Biodiversity associated with the constructional scleractinian *Lophelia pertusa* has been most intensively investigated, with coral habitats three times more speciose than adjacent areas (Henry and Roberts, 2007), with thousands of species living among *Lophelia* habitats (Roberts *et al.*, 2009). Animals such as deep-sea sponges that inhabit cold-water coral and similar habitats also produce important bioactive compounds such as those being commercially developed as anti-cancer treatments (Hogg *et al.*, 2010).

More than 75% of the Caribbean is covered by waters greater than 500 m depths, yet knowledge of this aspect of Caribbean marine biodiversity is remarkably low (Miloslavich *et al.*, 2010), and thus so is

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awareness of cold-water corals for this region. Deep-sea ecology, taxonomy and habitat mapping are vital scientific aspects to best inform the public, their governments and stakeholders about the state of marine natural resources and their conservation within the exclusive economic zones of Caribbean nations. Historic sediment profiling, photographic surveys and submersible dives were undertaken by the National Oceanic and Atmospheric Administration in the southern barrier reef region of Belize (James and Ginsburg, 1979). More recently, scientific co-ordination of mapping has been led by the Instituto Nacional de Estadistica, Geografia e Informática in Mexico, resulting in the production of the first bathymetric map of the northwestern Caribbean, inclusive of the Belizean EEZ, under the International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico (IBCCA) mapping project sponsored by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific, and Cultural Organization (http://www.ngdc.noaa.gov/mgg/ibcca/).

The December 2010 ban on bottom trawling across the Belizean exclusive economic zone (EEZ) goes a long way in protecting deep-sea fauna including corals, yet little can be done to protect Belizean waters from other anthropogenic activities such as hydrocarbon resource extraction, without even baseline knowledge about these animals and their habitats. Beginning with the IBCCA, higher resolution detailed acoustic surveys using multibeam echo sounder swath bathymetry and sidescan sonar will be instrumental in informing scientists, the public, government and stakeholders alike of the state of deep-sea habitats produced by cold-water corals in the Belizean EEZ and wider Caribbean as it has been in the North Atlantic (Roberts *et al.*, 2005, 2009; Huvenne *et al.*, 2010).

COLD-WATER CORAL RESEARCH IN THE CARIBBEAN, INCLUDING BELIZE

Targeted cold-water coral exploration in the wider Caribbean region has greatly increased over the last couple of decades, and has revealed the ubiquitous distribution of this fauna across the region (a detailed review is provided by Lutz and Ginsburg, 2007). The region has the highest species richness of deep-water Scleractinia (92 species), but these are quite vulnerable with 27% of species being endemic to the insular western Atlantic (Cairns and Chapman, 2001). Yet despite great advances in technological development, older historical research still underpins much our current state of the taxonomic knowledge regarding the cold-water coral fauna from the Caribbean Sea itself (e.g., Cairns, 1979, 1986 and references therein). More recently, significant advances in cold-water coral inventories and habitat mapping have been made largely at the Instituto de Investigaciones Marinas y Costeras in Colombia in collaboration with the Smithsonian Institute (e.g., Reyes *et al.*, 2005, 2009). With few exceptions, including the recent IBCCA, the Caribbean region also still lacks detailed habitat mapping, hydrographical and geological investigation of most coral habitats, including those off Belize. Thus, cold-water coral research in the Caribbean Sea itself greatly lags behind advances made in adjacent areas such as the Gulf of Mexico, Straits of Florida and the Bahamas (see Brooke and Schroeder, 2007; Lutz and Ginsburg, 2007; Ross and Nizinksi, 2007).

Submersible dives off Belize in the 1970s provided first glimpses of the fore-reef zones between Glover's Reef and the barrier reef, which revealed a large (30 cm diameter) unidentified hydrocoral on a sediment-covered rocky slope at about 240 m depth (image on p. 61 in James and Ginsburg, 1979). Other invertebrates were also reported including gorgonians, cerianthids, anemones, crinoids and sponges, as well as ophiuroids on hydrocoral branches (James and Ginsburg, 1979). Taxonomic investigations of the Caribbean deep-water scleractinian fauna revealed five cold-water coral species inhabiting Belizean waters greater than 200 m (Cairns, 1979, 1982; Table 1), all of which have North Atlantic and Gulf of Mexico distributions.

Table 1. Valid species (*) of deep-water (>200m) Scleractinia known from Belize.

Family Caryophylliidae
**Caryophyllia ambrosia ambrosia* Alcock, 1898
Caryophyllia cornuformis Pourtalès, 1868 (accepted as *Premocyathus cornuformis* (Pourtalès, 1868))
**Deltocyathus* sp. cf *D. italicus* (Michelotti, 1838)
**Deltocyathus moseleyi* Cairns, 1979; North Atlantic, Gulf of Mexico
**Premocyathus cornuformis* (Pourtalès, 1868)); North Atlantic, Gulf of Mexico
Family Flabellidae
**Javania cailleti* (Duchassaing and Michelotti, 1864); North Atlantic, Gulf of Mexico

COLD-WATER CORAL CONNECTIVITY IN THE NORTHWESTERN CARIBBEAN, INCLUDING BELIZE

The general biogeographic affinity of the cold-water coral fauna from Belize and the wider Caribbean is West Indian provincial (sensu Briggs, 1974; Cairns and Chapman, 2001). Inflow into the Caribbean arises from the surficial Caribbean Current. Notably, surface waters bathing Turneffe Island and Glover's Reef are connected to a deep-water corridor originating from the Honduras Bay Islands in the summer (Tang *et al.*, 2006), and Caribbean Current mesoscale eddies strongly affect the southern region of the Meso-American barrier reef (Shcherbina *et al.*, 2008). Down to about 50 m, this water mass is well mixed and approximately 27-28°C, upon which a steep thermocline down to about 200 m occurs with temperatures reaching 18°C. Below 200 m, the Belizean shelf is bathed by Caribbean Deep Water approximately 10-18°C (James and Ginsberg, 1979). The cold, low-salinity nutrient-rich Southern Ocean-derived Antarctic Intermediate Water (AAIW) is advected northwestwards from the North Brazil Intermediate Current and reaches the Caribbean from about 700-1100 m water depth: deeper still, an oxygen minimum layer at about 2000 m coincides with Upper North Atlantic Deep Water (NADW). Caribbean outflow through the Yucatán Straits into the Gulf of Mexico forms part of the Loop Current, which feeds into the Straits of Florida to reach the fast-flowing Gulf Stream.

Species composition of cold-water scleractinians and gorgonians are significantly controlled by water mass stratification, with assemblages closely tracking specific water masses such as AAIW and NADW (Arantes *et al.*, 2009). The widespread circulation of intermediate water masses in particular may be responsible for the close biogeographic affinities and species similarities of deep-water scleractinian assemblages between the western and southern Caribbean and Antillean regions (Cairns and Chapman, 2001). Even within species, cold-water corals such as the eurybathic solitary scleractinian *Desmophyllum dianthus* rarely migrate between water masses, and are thus highly differentiated or isolated from those inhabiting different depths (Miller *et al.*, 2011). It therefore highly likely that large-scale oceanographic features directly influence deep-sea marine biodiversity in the Caribbean region, including that of cold-water corals by increasing species richness and homogenizing cold-water coral fauna across wide geographic distances within a water mass, but increasing species turnover between water masses (Viana *et al.*, 1994; Arantes *et al.*, 2009; Miller *et al.*, 2011).

A CARIBBEAN DEEP-SEA CORAL 'GATEWAY'

Factors affecting or disrupting the source and flow of coral larvae must have downstream effects: the near continuous distribution of cold-water coral species particularly along the Antillean, southern and western Caribbean shelves and into the Gulf of Mexico and Straits of Florida (Lutz and Ginsburg, 2007) suggests that corals are broadly distributed here in part because of locally favorable hydrodynamic and sedimentary regimes, but also because of regionally continuous water mass circulation. For example, large-scale circulation patterns can genetically homogenize deep-sea species between the Caribbean, Gulf of Mexico and the Straits of Florida (Escobar-Briones *et al.*, 2010).

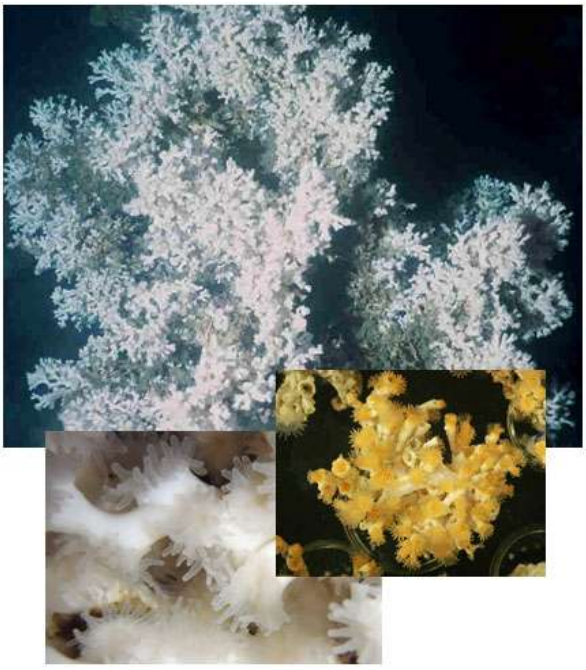

Figure 1. The constructional cold-water coral *Lophelia pertusa*. Colony size approximately 1m high. Inset: *in vitro* close-up images of extended polyps. All images copyright to Murray Roberts

To illustrate the importance of large-scale circulation in the biodiversity and biogeography of Caribbean cold-water corals, we can examine the occurrence of the constructional framework-forming species *Lophelia pertusa* (Figure 1). In the western Atlantic, it builds large reef frameworks along the continental southeastern Brazilian shelf, in the Straits of Florida, off the Bahamas and along the southeastern United States coast, and it also occurs off Venezuela, Colombia, the Honduras, and in the northern and eastern reaches of the Gulf of Mexico. This route of coral distribution broadly conforms to the circulation of AAIW, a cold low saline and

nutrient rich water mass. In contrast to those in the Caribbean Sea, cold-water coral habitats in all these regions are becoming increasingly well studied: many now have detailed palaeoceanographic, hydrographic, multibeam bathymetric, side scan sediment profiling and seismic data to accompany intensive species biodiversity inventories (see Brooke and Schroeder, 2007; Lutz and Ginsburg, 2007; Ross and Nizinksi, 2007). Recent initiatives driving this research include those driven by NOAA's Undersea Research Program and the Ocean Explorer Program, the international programme TRans-Atlantic Coral Ecosystem Study (TRACES), along with interdisciplinary collaborations involving hydrocarbon exploration surveys, and those arising from calls to examine impacts of the 2010 BP DeepWater Horizon oil spill.

Of relevance for the Belizean shelf is the flow path of AAIW, which could potentially be responsible for transporting coral larvae between the southern and northwestern reaches of the Caribbean. Should cold-water corals within Belize's EEZ become negatively impacted, coral communities downstream may be affected by lack of recruitment, which will include those in the Loop Current and the well-developed coral banks in the Straits of Florida, off the Bahamas and along the southeastern US coast. Intensive review of potentially harmful effects of hydrocarbon exploration, extraction and accidents led by the International Research Institute of Stavanger (Baussant *et al.*, 2011) highlighted the need to: (1) develop and validate threshold models of cold-water coral vulnerability and particle discharge; (2) collect and review cold-water coral data and mitigation measures; (3) develop monitoring guidelines for site surveys and drilling activities; and (4) fill in data gaps. Without even baseline knowledge of the deep-sea fauna and their habitats in the Belizean EEZ, not only can the potentially harmful effects of anthropogenic activities in deeper waters off Belize not be properly assessed, but wider-scale downstream effects of damage within this coral 'gateway' will not be known until it is too late, and any policy decisions will by premature and not fully informed.

There are some occurrences of *L. pertusa* in the Caribbean (p. 28 in Roberts *et al.*, 2009), but so far none have been reported within the Belizean EEZ. Another constructional coral, *Madrepora carolina*, has been recorded off Cozumel, Mexico (Fenner, 1999). *Lophelia pertusa* and another framework-forming coral, *Dendrophyllia alternata*, have been recorded very close by at a few hundred meters depth off Roatán, Honduras during the NOAA-led Deep Corals and Associated Species Taxonomy and Ecology (DeepCAST) II Expedition (P. Etnoyer, personal communication). *Lophelia* then re-appears in the Straits of Florida and possibly off Campeche Bank (Hübscher *et al.*, 2010): it is therefore very likely that *L. pertusa* occurs again somewhere between Roatán and the Straits of Florida in a Caribbean deep-sea coral 'gateway'. Given the proximity, bathymetry, previous investigations and circulation patterns, at the very least, one might expect *Lophelia* to occur again somewhere between Roatán and off Glover's Reef Atoll.

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NATURAL AND ANTHROPOGENIC CATASTROPHE ON THE BELIZEAN BARRIER REEF[1]

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ABSTRACT

The coral reefs that comprise the Belizean Barrier Reef face natural and anthropogenic threats over a range of spatio-temporal scales. On the flanks of the rhomboid shoals in the central shelf lagoon, the composition of coral assemblages remained static for at least several thousand years until the late 1980s. After 1986, an outbreak of coral disease eliminated staghorn coral, *Acropora cervicornis*, which for millennia had dominated the benthic assemblage and been the primary constructor of reef framework. A decade later in 1998, an episode of coral bleaching extirpated lettuce coral, *Agaricia tenuifolia*, which had replaced *Acropora cervicornis* as the dominant space occupant. In 2009, a strong earthquake obliterated half the living reef communities on the rhomboid shoals. Geological analysis yielded an estimated return time for an ecological event of that magnitude on the order of millennia. Although there is no demonstrable link between anthropogenic perturbation and the disease outbreak, human-induced global warming was at least partially responsible for the bleaching event. Truly long-term management of the marine resources of the rhomboid shoals must take into account rare natural catastrophes as well as anthropogenic perturbations. The imperative for long-term planning stands as a counterpoint to the expediency of immediate resource extraction for short-term gain.

INTRODUCTION

John Maynard Keynes famously said, "*The long run is a misleading guide to current affairs. In the long run we are all dead.*" A rational approach to marine policy turns Keynes's economic dictum of 1923 on its head: current affairs are a misleading guide to the long run. Degrading the Belizean Barrier Reef, a World Heritage Site, for profit over the next several decades is an inappropriate strategy, because unsustainable exploitation in the short term forces the public to relinquish the future benefits of their common inheritance. The conservation ethic compels us to scale protection to the lifespan of the Barrier Reef, not to the short lifespan of its human stewards and their even shorter-term interests.

In this essay, we review the ecological impacts of a recent series of large-scale disturbances in the central shelf lagoon of Belize. Based on the last several decades of catastrophic impacts on the system, we estimate the half-life of lagoonal reef communities. What is statistically likely to happen over the next 1,000 to 4,000 years—but could in fact happen this year or next—provides a strong and vibrant rationale for enhancing protection of the public trust.

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MILLENNIAL-SCALE STASIS AND RECENT VOLATILITY

The central sector of the shelf lagoon of the Belizean Barrier Reef, encompassing an area of approximately 375 km², is characterized by atoll-like ribbon-reefs, or rhomboid shoals (Figure 1). The uncemented frameworks of the rhomboid shoals are constructed of coral skeletons and skeletal debris packed in fine sediment. The sessile epibenthos consists primarily of corals, sponges, and algae, with ascidians and cyanobacteria as lesser components. These sessile organisms rest atop or are loosely buried in the sandy-mud to muddy-sand matrix (Macintyre and Aronson 2006). The primary herbivore is the abundant sea urchin *Echinometra viridis* (see Aronson and Precht, 1997; Aronson, 2002a, 2002b).

On many reefs of the insular Caribbean, the black-spined sea urchin, *Diadema antillarum*, was the most significant herbivore until its demise from an unknown, water-borne pathogen in 1983-1984 (Lessios, 1988). In fore-reef habitats of the Belizean Barrier Reef, by contrast, this echinoid species exerted a minor influence compared to herbivorous fishes prior to its regional mass mortality (Lewis and Wainwright, 1985; Levitan, 1992). Neither *D. antillarum* nor herbivorous fishes were or are currently strong interactors on the rhomboid shoals (Aronson and Precht, 1997). The demersal reef-fish assemblage consists primarily of small blennies (Blenniidae), gobies (Gobiidae) and, rarely, butterflyfish (Chaetodontidae). The most common large species is the gray angelfish, *Pomacanthus arcuatus* (Pomacanthidae), which is a spongivore.

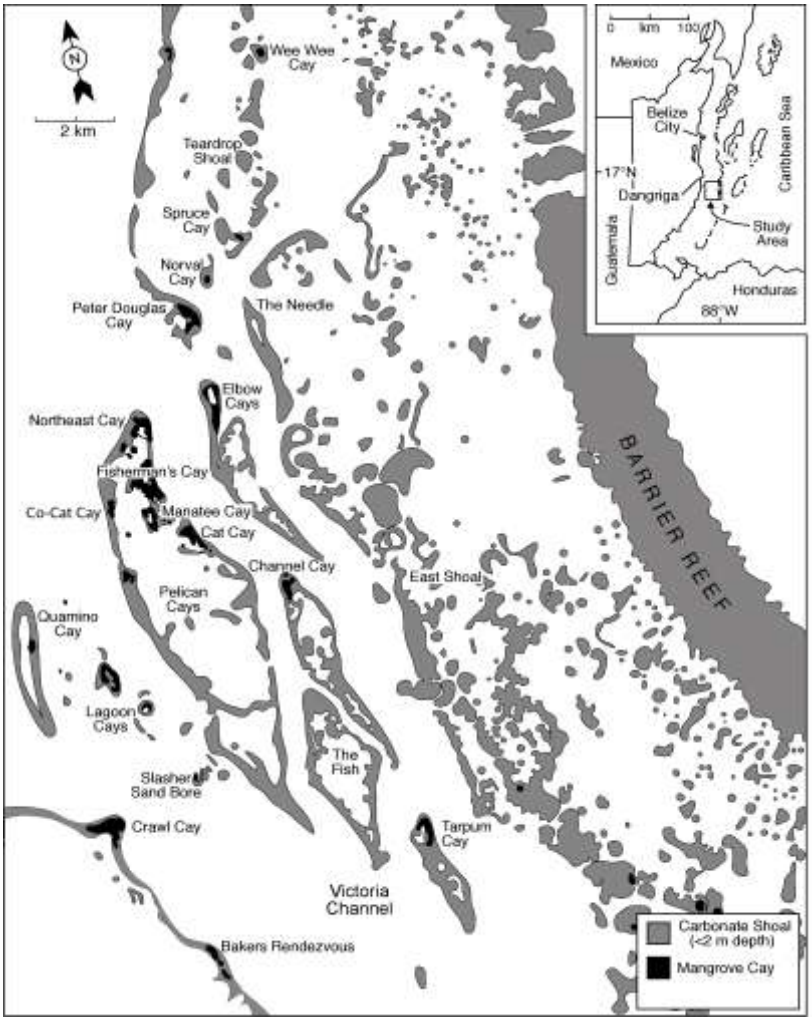

Figure 1. Map of the central shelf lagoon of the Belizean Barrier Reef, showing the locations of the rhomboid shoals. This area is protected as part of the South Water Caye Marine Reserve, which was established in 1996. Drawn by T.J.T. Murdoch from a satellite image.

From at least as early as the 1970s through our first observations in 1986, the benthic communities along the steep outer flanks of the rhomboid shoals were dominated by the staghorn coral, *Acropora cervicornis* (Aronson and Precht, 1997). After 1986, *Acropora cervicornis* was nearly extirpated in a regional outbreak of white-band disease (WBD). WBD is an infectious bacterial syndrome that is poorly characterized in terms of pathogenesis and etiology. The disease is specific to corals of the genus *Acropora*, and it wiped out populations of *Acropora cervicornis* and the elkhorn coral, *Acropora palmata*, in subtropical and tropical reef systems throughout Florida, the Bahamas, and the Caribbean from the late 1970s through the early 1990s (Aronson and Precht, 2001). WBD was the first catastrophic impact on the rhomboid shoals in recent decades, and it also destroyed acroporid populations on the seaward-facing fore reef of the Belizean Barrier Reef (Aronson and Precht, 2001). Herbivory by *E. viridis* controlled the growth of algae, which promoted recruitment and growth of the lettuce coral, *Agaricia tenuifolia*, on the dead skeletons of *Acropora cervicornis*. By the mid-1990s, *Agaricia tenuifolia* had become the dominant space occupant of the flanks of the rhomboid shoals.

Push-cores, which were extracted from 20 stations in the central lagoon during 1995-2000 and radiocarbon-dated, demonstrated that *Acropora cervicornis* was both the dominant coral and primary framework builder of the rhomboid shoals for millennia. The destruction of *Acropora cervicornis* by WBD and the transition in dominance to *Agaricia tenuifolia* after 1986 were unprecedented events in at least the last 3,000-4,000 years (Aronson and Precht, 1997; Aronson *et al.*, 2002a). The cores also revealed that herbivory by *E. viridis* had been an important and constant force in the ecology of the rhomboid shoals for thousands of years.

A worldwide coral-bleaching event in 1997-1998, driven by the El Niño/Southern Oscillation (ENSO) and augmented by global warming, affected the Belizean Barrier Reef during the late summer and fall of 1998. In the central lagoon, virtually all the *Agaricia tenuifolia* on the rhomboid shoals bleached and subsequently died (Aronson *et al.*, 2000, 2002b). Because the rise to dominance of *Agaricia tenuifolia* was unprecedented on a millennial scale, so was its demise from this second catastrophe. From 1998 to 2009, the dead skeletons of *Agaricia tenuifolia* were colonized by the encrusting chicken-liver sponge, *Chondrilla caribensis*, and to a lesser extent by macroalgae, cyanobacteria, ascidians, and other sessile epibenthos. Recruitment of corals was severely depressed (Aronson *et al.*, 2002a; in press). The spongivorous *P. arcuatus*, which bite *Chondrilla* only occasionally (J. Wulff, personal communication), were apparently unable to control the spread of *C. caribensis* because they could not respond either behaviorally or numerically to sponge growth on the enormous quantity of bare space opened by the mass mortality of *Agaricia tenuifolia*.

In May 2009 a strong earthquake in the Caribbean Sea, centered 64 km northeast of Isla Roatán, Honduras, shook the Belizean Barrier Reef. Roughly half the 20 reef communities that had been observed and documented prior to the earthquake (Aronson *et al.*, 2002a; 2005) were destroyed in less than a minute by the catastrophic failure and avalanching of their slopes. Recovery of the benthic communities on the failed slopes will depend on recruitment from nearby reef communities that were not destroyed, and on larval sources further upstream.

The push-cores (Aronson *et al.*, 2002a), which had been extracted prior to the earthquake, contained well-ordered sedimentary packages, suggesting sequential deposition. There was no evidence of widespread slumping or slope-failure. Radiocarbon dates from the bottoms of the cores ranged from centuries to almost 4,000 years before present, reflecting variability in the vertical growth rates of the reefs. Based on the oldest bottom date, the return time of an event of this magnitude in the central shelf lagoon of Belize is at least several thousand years.

Discussion

In 2009, UNESCO inscribed the Belizean Barrier Reef on its *List of World Heritage In Danger* (http://whc.unesco.org/en/list/764; http://whc.unesco.org/en/news/530). This listing was based primarily on illegal mangrove cutting and development in the rhomboid shoals (Macintyre *et al.*, 2009), which are part of the South Water Caye Marine Reserve. Such activities cause direct physical damage, of course, but they also have cascading impacts on the marine biota through siltation and erosion, and by compromising the integrity of the reef framework. Both sessile and mobile assemblages are negatively affected, including important interactors such as corals, sponges, fishes, and sea urchins.

Management of coral-reef resources must take into account immediate, local threats from human activities, including mangrove cutting and the proposed oil-drilling activities; as well as the larger-scale, longer-term threats of anthropogenic global warming and ocean acidification. Two unprecedented ecological catastrophes—the outbreak of white-band disease after 1986 and the coral-bleaching episode of 1998—underscore the fragility of the reef ecosystems that comprise the Belizean Barrier Reef. Although there is no demonstrable link between WBD and human perturbation of the marine environment, the worldwide bleaching event of 1997-1998 was connected not only to ENSO, but to anthropogenic climate change. The rhomboid shoals face an additional, long-period threat: the tectonically driven failure of reef-slopes. Long-term visions of marine conservation must account for the high probability of a repeat of the earthquake of 2009 and the losses associated with that event. Scaling management appropriately to the lifespan of reefs on the rhomboid shoals means enhancing management of the South Water Caye Marine Reserve, to compensate for the local tectonic regimes, whatever else the future may hold and however well society is able to address climate change.

Science is not a democratic process: we do not vote on the facts. The policy that results from that science, however, should be formulated according to the will of the people. Belizean citizens, acting through their legislators, ought to determine whether to manage the Barrier Reef for viability over the next decades, the next centuries, or the next millennia. In our view, protections should not be downgraded for short-term economic gains. To the contrary, we recommend that those protections be extended beyond current levels, with a view to long-term survival of the marine resources of Belize and the ecosystem services they provide.

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DECLINING REEF HEALTH CALLS FOR STRONGER PROTECTION NOT ADDITIONAL POLLUTION FROM OFFSHORE OIL DEVELOPMENT[1]

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ABSTRACT

The Belize Barrier Reef Complex is the longest barrier reef in the Western Hemisphere. It is the core of the spectacular Mesoamerican Reef (MAR) system that includes diverse reef types, previously considered to be among the healthiest in the Caribbean. A combination of overfishing, coastal development, pollution, coral bleaching, disease outbreaks and hurricanes have reduced reef health in the last few decades. The 2010 Report Card issued by the Healthy Reefs for Healthy People Initiative, a collaboration of over 30 international, regional, national and local organizations, found that only 1% of the 130 reefs surveyed are now in 'very good' condition; 8% are 'good' 21% 'fair', 40% 'poor', and an alarming 30% of reefs are now in 'critical' condition. These results are based on 130 reefs surveyed (in Mexico, Belize and Honduras) and evaluated with four indicators of reef health (coral cover, fleshy macroalgal cover, herbivorous fish biomass and commercial fish biomass), forming a "simplified" Reef Health Index (SIRHI).

In addition to the overall health of the reef, scientists are concerned about the increasing number of marine species considered in danger of extinction. In 2006, there were 5 critically endangered, 6 endangered, and 16 vulnerable marine species in the MAR. Despite strengthened conservation efforts, the changes in only four years are discouraging. In 2010, the numbers have grown to 7 critically endangered, 7 endangered, and 17 vulnerable marine species in the MAR. Many of these species have actually not been reevaluated since 2006.

There are important management efforts underway aimed at stemming the tide of decline. Belize has recently enacted several important fisheries regulations, including the full protection of key reef grazers (parrot fishes), an increase in the area of fully-protected replenishment reserves, and a ban on spearfishing inside all marine reserves. In addition, the Belize Coastal Zone Management Authority and Institute is currently preparing the Coastal Zone Management Plan for Belize. It should be completed by the end of 2012 and will present a balanced approach to sustainable resource use, including marine and coastal zoning schemes.

INTRODUCTION

The Mesoamerican Reef (MAR) stretches over 1,000 km and includes the Western Hemisphere's longest barrier reef in Belize, as well as fringing reefs off Mexico's Yucatan Peninsula, along the mainland coasts of Guatemala and Honduras, as well as around the Bay Islands, Honduras. These diverse reef complexes and neighboring seagrass meadows, deep and shallow lagoons, and mangrove forests, form a dynamic mosaic of marine biodiversity. The overall ecoregion covers approximately 464,419 km^2, with 192,648 km^2 in watersheds and 271,771 km^2 in a variety of marine habitats (HRI, 2010). In Belize alone, the reef and mangrove ecosystems were estimated to contribute approximately 395-559 M USD in goods and services each year, primarily through marine-based tourism, fisheries and coastal protection (Cooper *et al.*, 2008).

MATERIAL AND METHODS

The data presented in the 2008 and 2010 Report Cards was collected using one of two methodologies (Almada-Villela *et al.*, 2003; AGRRA, 2006). Both methodologies employ ten 30 meter belt transects for

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assessing fish populations. Both of these methods use line transects for coral and benthic assessments, with AGRRA (2010) using six 10 m linear intercept transects and Almada-Villela (2003) using six 25 m point intercept transects (spaced every 25 cm).

RESULTS AND DISCUSSION

A few decades ago the Mesoamerican reef was considered to be in better condition than most other reefs of the Caribbean—but this distinction is now uncertain. Many of the reef health indicators (particularly for fish abundances) are now in poor condition (HRI, 2010). The 2010 Report Card for the Mesoamerican Reef found that only 1% of reefs are in very good' condition, 8% are 'good', 21% are 'fair", 40% 'poor', and an alarming 30% of reefs are now in 'critical' condition (HRI, 2010; see Figure 1). The results are based on 130 reefs surveyed from Mexico Belize and Honduras and evaluated with four indicators of reef health, i.e., coral cover, fleshy macroalgal cover, herbivorous fish biomass and commercial fish biomass; which are compared to a regionally standardized ranking criterion for each indicator (HRI, 2010).

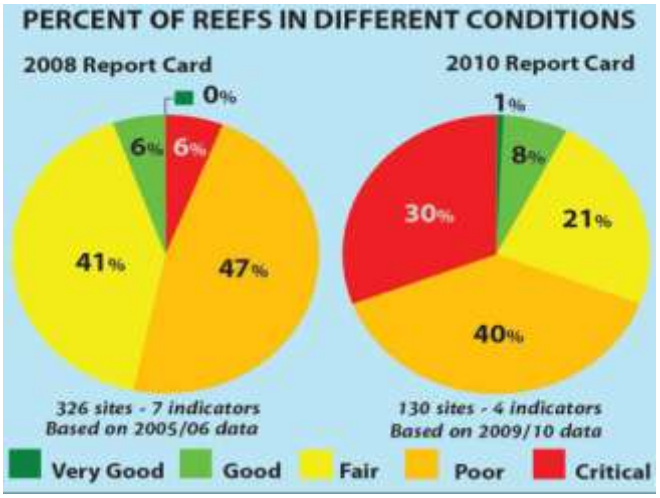

Figure 1. Percent of Reefs in Different Categories of Health Status Across the Mesoamerican Reef (HRI, 2010).

Reef condition was assessed with four indicators of reef health, *viz.*: coral cover, fleshy macroalgal cover, herbivorous fish biomass and commercial fish biomass; forming a "simplified" Reef Health Index (SIRHI). The regional SIRHI score was 2.1 for 2009 data (ranked as 'poor") *vs.* 2.7 for 2006 data (ranked as "fair'). Fifty of these sites were evaluated in 2006 and again in 2009, finding that 62% of these reefs declined in health status as compared to only 12% that improved. The declines in reef health were mainly attributed to declining commercial fish biomass (from 1017 to 570 $g \cdot 100m^{-2}$) and herbivorous fish biomass (from 2415 to 1196 $g \cdot 100m^{-2}$), and increasing macroalgae from 10% to 18%. The encouraging news is that the coral cover improved, from 13% to almost 19%, as there were no major coral disturbances in this interval (coral bleaching, hurricanes, etc).

In 2006 there were 5 critically endangered, 6 endangered, and 16 vulnerable marine species in the MAR. Despite strengthened conservation efforts, the changes in only four years are discouraging. In 2010, the numbers have grown to 7 critically endangered, 7 endangered, and 17 vulnerable marine species in the MAR. Many of these species have actually not been reevaluated since 2006 (IUCN, 2010).

There are many reasons for the decline in reef health occurring at the local, regional and global levels. The long-recognized main threats (over-fishing, coastal development, inland clearing agriculture, and climate change) continue with growing intensity and are now joined by the new threats of invasive lionfish—now found virtually everywhere in the MAR, and offshore oil drilling (HRI, 2010).

Despite the virtual laundry list of threats, climate change is viewed as a significant factor in the current decline of corals, in particular. The long term effects of coral bleaching and ocean acidification are difficult to measure, but mounting evidence is indicative of lasting impacts. The Mesoamerican Reef experienced its first widespread documented bleaching event in 1995 (McField, 1999), followed by the more severe and widespread bleaching event in 1998 and a less severe, but also widespread event in 2005 (McField *et al.*, 2008). The impact of the 1998 bleaching event was unprecedented in the past century, based on measured reductions in skeletal growth rates in the dominant reef builder, massive *Montastraea faveolata* corals, over the past 75-150 years (Carilli *et al.*, 2009). Similar long-term reductions in coral growth rates have been recorded for other reefs such as the Great Barrier Reef (De'ath *et al.*, 2009), Thailand (Tanzil *et al.*, 2009) and Panama (Guzman *et al.*, 2008).

In addition to the stress of rising water temperatures, as atmospheric carbon dioxide becomes dissolved in seawater it causes a reduction in pH that requires most calcifying organisms to expend additional energy for calcification under lower pH. A recent laboratory study found that crustose coralline algae (important for cementing the reef and facilitating the settlement of coral recruits) and some corals were also more affected by bleaching under higher CO_2 (Anthony *et al.*, 2008). No widespread *in situ* measurements of pH and carbonate saturation state are known to have occurred in the MAR in the last decade, and such are needed to establish actual chemical shifts that may be occurring.

Management efforts to stem the tide of declining reef health

There are important management efforts underway aimed at stemming this tide of reef decline. Belize has recently enacted several important fisheries regulations, including the full protection of key reef grazers (parrotfishes), an increase in the area of fully-protected replenishment reserves, and a ban on spearfishing inside all marine reserves. In addition, in late 2010 the Government of Belize the permanently banned all shrimp trawling in Belizean waters. Currently the Belize Coastal Zone Management Authority and Institute is preparing the Coastal Zone Management Plan for Belize. It should be completed by the end of 2012 and will include marine spatial planning for the entire coastal zone of Belize.

Significant financial and human resources are expended annually in the MAR to support these reef management new fisheries regulations, the full protection of sharks in Honduras, from overfishing, improvement of watershed management, and protection or replanting of coastal mangroves, are proven tools to improve ecosystem functioning. However, they may also actually increase the thermal tolerance of corals to bleaching stress and thus the associated likelihood of surviving global warming and future bleaching events (Carilli *et al.,* 2009).

One innovative adaptation program underway in Belize involves the propagation of two species (*Acropora palmata* and *A. cervicornis*) that were formerly the most common corals in Belize and the Caribbean. Their abundance has been reduced by over 98% Caribbean-wide, due to climate-related impacts, including bleaching, disease and hurricane damage, in just a few decades. These endangered species are now being grown in six "nursery" areas where clippings (over 3,000 to date) are being replanted on the reef (Carne, 2011). Seventeen distinct genotypes have been identified and are being monitored through bleaching events to help identify bleaching-resistant genotypes for further propagation (Carne, 2011).

These many commendable management efforts underway within the region stand in stark contrast to the indiscriminant offshore oil concessions in Belize, which do not recognize legally 'protected' areas or restricted activities. The potential development of an offhore oil industry poses a serious threat to the reef's ability to regain its former health. Seismic testing activities are scheduled in 2011 with exploratory drilling scheduled as early as 2012. Meanwhile, the National Oil Spill Contingency Plan has languished as an incomplete and elusive 'draft' document since the early 1990's.

Regional offshore oil exploration: a potentially fatal blow

The threat of offshore oil drilling to marine ecosystems, even substantial distances away from the rigs, has been horribly demonstrated through the April 2010 Deep Horizon spill in the Northern Gulf of Mexico. That environmental, social and economic catastrophe has catalyzed discussion across the Mesoamerican region about the current status and risks of offshore drilling. The following summarizes our best available knowledge as to the status of oil concessions and activities in the MAR region, as described in HRI (2010).

In Mexico, the state-owned oil company, Petróleos Mexicanos (PEMEX), has continued and intensified the exploratory activities in the coastal plain, continental platform and deep waters of the Gulf of Mexico, where the acquisition and interpretation of the geological and geophysical information have permitted the estimation of the extent of petroleum potential in all of Mexico (Figure 2). The exploratory strategy is directed to the basins of the Southeast (zone 5) and the Deep Gulf of Mexico (zone 6). Prior to the Deep Horizon spill, the Ixtoc oil rig explosion was the world's largest oil spill, occurred in zone 5. It was caused by a blow-out of an exploratory well, IXTOC, drilling in 150 feet (50 m) of water which belched crude oil for 297 days, dumping nearly 3 million barrels (126 million gallons/477 million liters) of oil into the southern Gulf of Mexico, some of which eventually washed up on the Texas coast. The PEMEX strategy continues focusing on the exploitation of known reserves in the Gulf of Mexico, with no apparent exploratory strategy focused on the Mesoamerican Reef area for the near future.

In Guatemala, there are currently 12 areas that have been identified for oil and gas exploration, and six of them will be open to tender for concessions shortly. Although there are three sites in the Pacific Ocean, these will not be included in the tender offer (Figure 3). The Vice-Minister of Mining and Hydrocarbons recently indicated that the tender process had been delayed because some of the zone boundaries were modified to avoid protected areas. This boundary redefinition occurred after a much publicized reauthorization of a terrestrial oil-drilling license inside the Laguna del Tigre Protected Area in the Maya Biosphere Reserve, Peten, which was considered by several sectors as illegal. There are no stated plans or existing concessions for offshore oil exploration in the Caribbean.

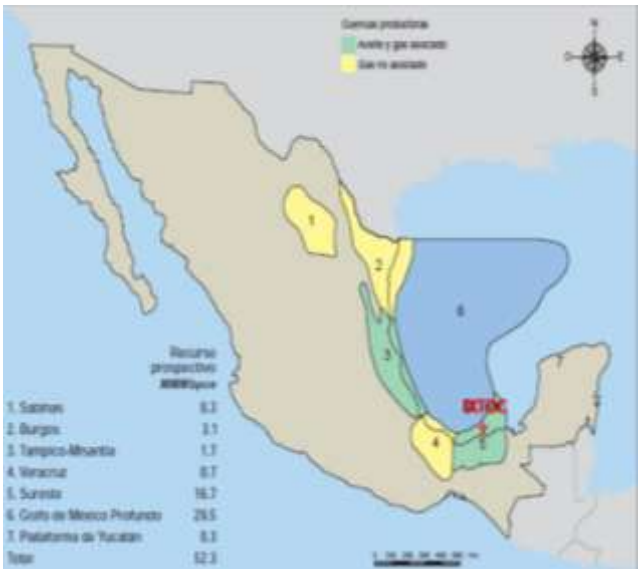

Figure 2. Mexico's Offshore Oil Concessions in the Atlantic (adapted from www.pemex.com).

Honduras has been debating a new law to regulate all oil exploration and exploitation since February of 2009. The National Congress has been swamped with requests from environmental and social groups to limit oil prospecting within the boundaries of protected areas, and establish safeguards and economic guarantees to remediate any impacts on natural resources on which the communities depend. Oil companies, on the other hand, are requesting to expand prospecting sites to include protected areas as well as continental waters within the country's EEZ.

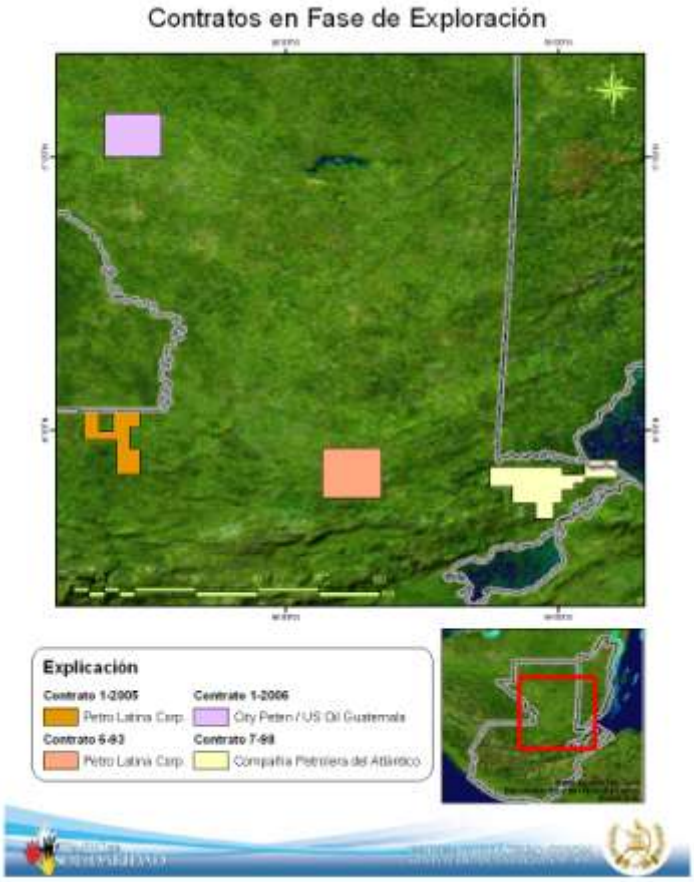

Figure 3. Guatemala's Oil Concessions (from the Ministerio de Energía y Minas http://www.mem.gob.gt).

Belize has the most prolific concession strategy in the region (see Figure 4), with the entire offshore marine territory being divided up into concession blocks, with seven active offshore concessions in 2011. Seismic testing is currently or soon to be underway in several blocks, while exploratory wells are planned for 2012 at the earliest. The Belize Coalition to Save Our Natural Heritage, an alliance of approximately 40 grassroots, business, labor and environmental groups, has called on the government to change its policy of exploitation in the offshore and in protected areas and improve environmental and safety management requirements in the remaining areas. The group has recently attained signatures in order to force a public referendum on the issue of whether or not to ban offshore oil exploration and exploration inside protected areas.

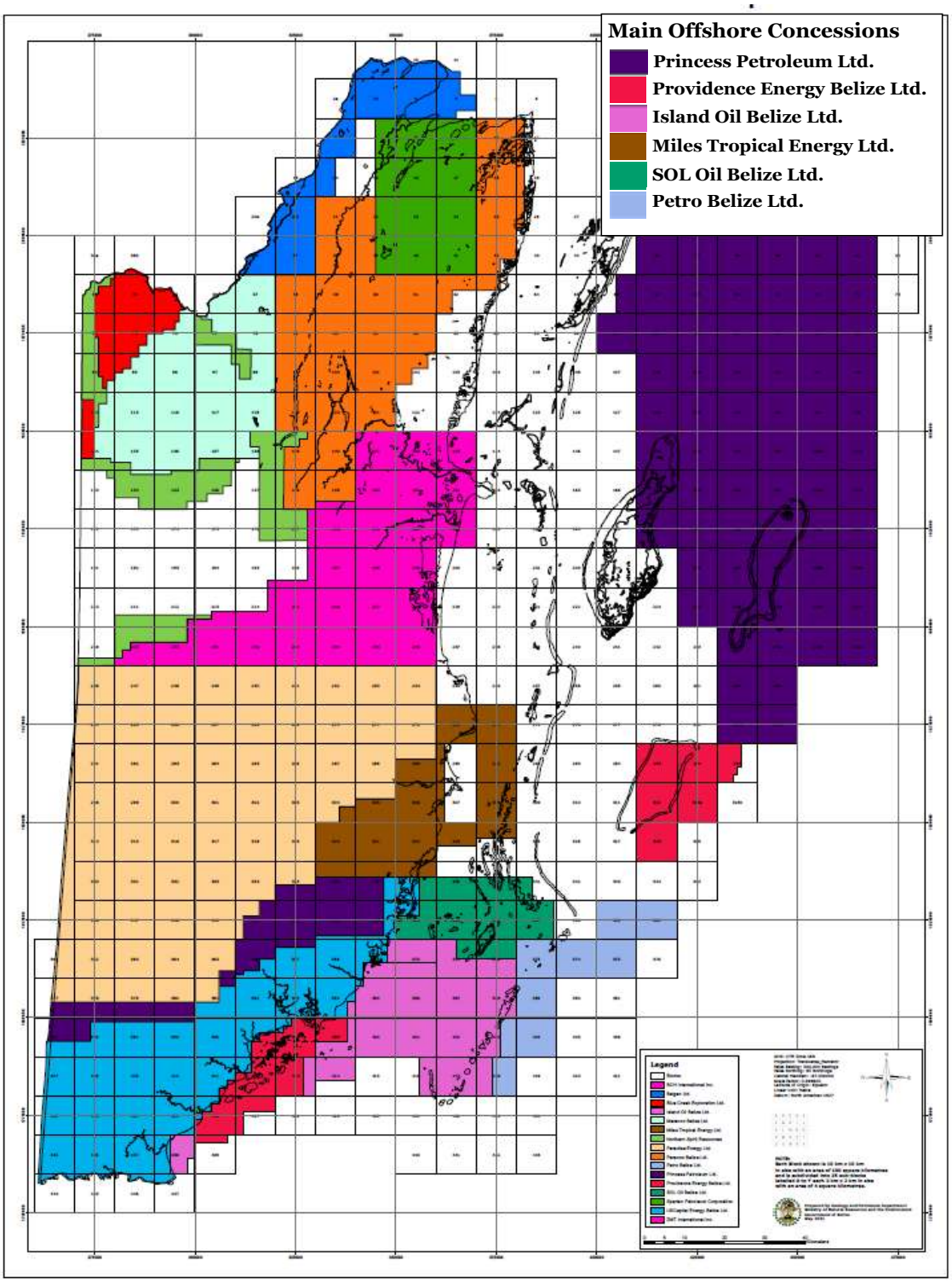

Figure 4. Belize's Oil Concessions July 2011. Source Geology and Petroleum Department. Government of Belize.

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FISHERIES AND TOURISM

FISHERIES BASED ON BELIZEAN BIODIVERSITY: WHY THEY'RE SO VULNERABLE TO OFFSHORE OIL EXPLORATION[1]

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ABSTRACT

Coral reefs are host to phenomenal biological diversity and Belize stewards the crown jewel of coral reef environments in the Caribbean, the heart of the Mesoamerican Reef system. Recent studies underscore the importance of the interconnectedness among its elements to overall system function and resilience. Genetically, the MAR fishery populations are very strongly self-connected; odds are that most of the fishes caught in Belize as well as the corals they live amongst are born of Belizean parents. Belize fisheries are supported by a network of habitats, incompletely known, whose function in fisheries production centers on this interconnectedness. Daily movements by fishes unite seagrass, mangroves, and coral reefs, promoting nutrient flow among habitats and building fisheries. Layered upon this are annual and inter-annual patterns in which fishes shift habitats across the continental shelf. As they mature, many species culminate in an adult existence centered on the reef. Any threat to the ability of fishery species to progress through their complex life histories is a threat to the fisheries themselves. Large fishes and staple species such as Nassau grouper are in danger of disappearing, and sixty-five percent of the Belizean reef domain is in poor to critical condition. Against this backdrop, offshore oil extraction represents an additional threat that the system is not currently prepared to accommodate.

INTRODUCTION

Coral reefs are host to the lion's share of earth's marine species diversity. Belize stewards the crown jewel of coral reef environments in the Caribbean: the heart of the Mesoamerican Barrier Reef complex (the MAR). The biological richness of Belize's continental shelf ecosystem supports the people of Belize by delivering wealth to the economy, to the culture and daily quality of life of the Belizean people. Healthy coral reef habitat and the availability of good fishing are paramount among the ecosystem services that the reef provides. Fishing is a source of food, the basis of many livelihoods in the food, tourism, and export sectors, and it is of enormous cultural and recreational significance to Belizean citizens (Calderon *et al.,* 2004). Fishing is at the core of coastal living in Belize, and coral reefs are the foundational habitat for these fisheries. However, the Belizean coral reef is just the most celebrated part of a network of marine and terrestrial habitats that must all work together for a healthy fishery to persist. Mangrove forest and seagrass beds are the more obvious among these supporting habitats (Vermeij *et al*., 2006), but submarine mud and sand flats, littoral forest, riparian forest, and upland habitats all the way to the mountains—even the mountains of Honduras—all play a role in the health of Belizean fisheries (Almada-Villella *et al.,* 2002). The integrity of this entire landscape—the whole MAR from Mexico to Honduras, Cozumel to Roatan—influences Belizean fisheries. A breakdown in good stewardship anywhere within the MAR can degrade living resources in Belize, and *vice versa*.

The marine environment of Belize is now quite well known from a whole-system perspective, but this is a recent development. Several large, comprehensive studies of the biology and socioeconomics of the Mesoamerican Barrier Reef complex carried out over the last decade have underscored the importance of the interconnectedness among its elements and compartments, including human dependencies (Cinner *et*

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al., 2009). These projects include the Mesoamerican Barrier Reef Study (MBRS), the Belize portion of the Coral Reef Targeted Research program of the World Bank (www.gefcoral.org), the Belize portion of Reefs at Risk and Reefs at Risk Revisited (www.wri.org/publication/reefs-at-risk-revisited), Healthy Reefs for Healthy People (www.healthyreefs.org), and most recently, the Belize Node of the Marine Management Area Science program (MMAS) of Conservation International. The Smithsonian Institution produced a steady string of discoveries and long-term monitoring data from its Carrie Bowe Caye Marine Laboratory. Perhaps the most interesting developments of recent years are the founding of the Environmental Research Institute (ERI) at the University of Belize, and the resurrection of the Coastal Zone Management Institute. Most of the evidence cited in this paper emerged from the MMAS project conducted between 2005 and 2010 (see www.science2action.org).

Recognition that commercial and recreational fisheries depend upon an intact coastal ecosystem is part of a growing movement toward 'ecosystem-based management' or EBM (Leslie and McLeod, 2009). The production of fishes to catch is not the only important ecosystem service relying on coastal marine habitats. Increasing the values derived from other sectors such as tourism, real estate, or energy, may not be invariably good for fisheries, and can even be in direct conflict. These trade-offs are complex and play out in surprising ways over time, but what is clear is that many different sectors of the Belize economy are similarly founded upon the ecological health of the coastal landscape. Tourism, real estate, and fisheries all require an intact coral reef and the coral reef in turn benefits from mangrove forests, seagrass beds, and healthy watersheds. Most forms of economic development exact a cost in terms of environmental health, and the goal is usually to minimize its magnitude and duration (www.science2action.org). Coastal real estate development in Belize usually involves the clearing of mangrove forest and the destruction of coral reefs, with an associated loss in current fishery value and future fisheries production potential. Indeed, land conversion from forest to other uses anywhere in Belize will ultimately affect the reef via sediment and pollutant runoff into rivers, and eventually, the lagoon. Riparian and mangrove forests can reduce this cost, thus inexorably linking the costs and benefits of upland and coastal development.

Oil is different. The extraction of fossil fuels such as petroleum depends only upon the remains of organisms that have been dead for millions of years. The ecological health of the reef is not necessary to support the generation of wealth from oil. Furthermore, living coral reefs are acutely vulnerable to activities associated with oil extraction. In one of many ironies, fossil coral reef formations sometimes serve as reservoirs for oil, enough so that the early studies of many living reef ecologists were supported by the oil industry. In any event, the trade-off between fisheries and oil is difficult to manage in the biodiverse, highly interconnected, and vulnerable coastal tropics where shallow coral reefs occur. Here we briefly discuss the nature of these connections. Each type of connection strengthens the fisheries production potential of Belize. By the same token, each is also a point of vulnerability, bound in a web of mutual dependence upon Belize's diverse marine species pool.

CONNECTIONS AMONG SPECIES POPULATIONS

Most species of marine life in Belize pass through some kind of larval life history phase during which they float on ocean currents, imbuing them with the potential to spread great distances. Until recently, biologists thought that they routinely did so, such that even populations of a species up to thousands of miles apart would remain closely connected, exchanging larvae frequently (Mumby, 2006). This would also mean that, should anything go amiss with a local coral or fish population, it would not be long before new individuals would float in from afar and reestablish the species in that place. While this remains a possibility, new data indicate that this is very much the exception rather than the rule. A few species routinely stay a very long time in the plankton—up to eighteen months or even longer—and have well-connected populations across great distances, e.g., the black durgon triggerfish and spiny lobsters. But, most, despite a capacity to wander, are geared to return to their birthplaces, a proven environment where their parents evidently prospered long enough to give birth to them. Scientists refer to such species as having a small 'dispersal kernel'. Several scientists in both the CRTR and MMAS projects focused on measuring connectivity and species endemism, two sides of the same evolutionary coin.

The result? The MAR is very strongly self-connected, dispersal kernels for several important fishery species are small, and odds are that most of the fishes caught in Belize, and most likely the corals they lived amongst, were born of Belizean parents. For example, Nassau grouper exhibit strong parent-offspring connectivity associated with position (i.e., country) within the MAR. Truly telling is the burgeoning list of species known only from the MAR, or even just within a small region of it. The wrasse

Halichoeres socialis, toadfishes in the genus *Sanopus*, several small gobies, and the Belizean blue hamlet *Hypoplectrus* sp. are among those species largely or entirely restricted to the nearshore waters of the MAR. Endemism is not possible without local retention of larvae. Some have not been seen outside the barrier reef (e.g. *H. socialis*)—any such species would be at special risk from the toxic effects of either petroleum or watershed-derived pollutants (P.S. Lobel, J. Randall, unpublished data; P.S. Lobel, L. Lobel, J. Randall, unpublished data). The fact that marine population structure is more local means that healthy populations must be maintained within areas the size of Belize, and smaller, to keep fisheries productive. Restoration of local populations via larval spillover from the rest of the Caribbean would take too long. Belizeans hold their future within their own hands.

CONNECTIONS AMONG HABITATS (VIA SPECIES' LIFE HISTORIES)

Belizean fisheries draw from a rich regional pool of nearly 1,600 fish species, of which roughly one third can reasonably be expected to occur in coastal waters, at least, on occasion (Taylor *et al.*, 2007). In addition, several invertebrates that spend part or all of their lives in the sea support major (spiny lobsters, *Panulirus* spp.; queen conch, *Strombus gigas*; several shrimp species) or minor (but locally valued, e.g., land crab) fisheries. The marine fishery itself is very diverse, and for convenience can be thought of as having, at least, the following components: table and commercial fisheries for the groupers, snappers and grunts; queen conch; lobster; shrimp; pelagic game sport fishery (dolphin, mackerels and wahoo, tunas, billfishes); grand slam fly sport fishery (tarpon-bonefish-permit); inshore and reef sport fishery (snook, reef fishes); miscellaneous crab fisheries (sea and land). There are also illegal fisheries for shark, and for lobster, conch, groupers and snappers out of season and in protected areas (see Zeller *et al.*, this volume), and some persistent poaching of sea turtles, manatee, and possibly crocodiles (both American and Morelet's, the latter endangered). Very few of the fishery species spend their entire life histories in just one place or habitat. Instead, nearly all require distinct juvenile, adult, and reproductive habitats. Mangrove forests and seagrass beds are the best known of these supporting habitats, but other types of seabottom that may seem a wasteland to the casual human observer are of enormous importance to the fishery (Verweij *et al.*, 2006). For example, as juveniles, Nassau groupers frequent coral cobbles with a light covering of seaweed, a habitat otherwise rated at a very low value, or overlooked entirely.

Most important to the local way of life are Belizean table fishes. These are dominated by three fish families: the grunts, the groupers, and the snappers, bolstered by a few of the larger species of wrasses, triggerfishes, porgies, and others. The three primary families are species rich in Belize, whose waters, according to FishBase (www.fishbase.org, June 2011 version), host 19 grunt species (Haemulidae), 15 snappers (Lutjanidae and Inermiidae), and 33 groupers (Serranidae). Most of these are common in shallow waters, but some are pursued by fishers into the darker waters several hundred meters deep off the barrier and atoll reef faces. Experienced Belizean fishers know each of these species well and they also know that each exhibits a unique life history and behavior. As adults, most are associated with coral reefs for at least a part of each day. Typical predators are nocturnal or crepuscular feeders, spending daylight hours either resting quietly or engaging in social behavior on the reef (adult groupers and snappers), or shoaling up in daytime resting aggregations (grunts, some snappers; Nagelkerken and van der Velda, 2004). It is these resting aggregations that help draw tourists to Half Moon, Hol Chan, and Laughing Bird Marine Reserves (B. Shank, L. Kaufman, unpublished data). At night, the resting schools fan out in organized migrations into seagrass beds and other nearby habitats, where they feed on small invertebrate and fish prey. Upon returning to the reef, they digest and void, supplying nutrients to the reef community. Day resting fishes also aggregate amongst red mangrove roots around the peripheries of mangrove forests, ranging out over adjacent seagrass beds by night to feed. Thus, diel movements unite seagrass, mangrove, and coral reef habitat, causing flow among habitats not only for fish biomass, but also nitrogen and other essential nutrients. As this story plays out below the water's surface, something similar goes on above water with the birds. Pelicans and wading birds that roost in mangrove crowns by night forage over seagrass by day, feeding heavily on marine prey and then enriching their roosting sites with imported marine-derived nutrients.

The daily cycle of habitat connectivity is layered upon an annual and inter-annual pattern in which fishes shift habitat as they mature. We are in the midst of a long-term study of habitat use by commercially important grunt, snapper, and grouper species. We have been inferring their life history movements in Belize in three ways. First, we can survey the species and size composition of a fish community using a simple visual census technique, and then compare these data from study sites in different habitats and locations across the Belize continental shelf system. In addition, we take a bit of muscle tissue from

sampled individuals, and examine it in a mass spectrometer to determine its carbon and nitrogen stable isotopic ratios. This tells us roughly what a fish has been eating and where (what level on the food chain, and whether it is feeding on the sea bottom or up the water column). So far, these data support the story of juvenile fishes feeding in or over seagrass, and using mangroves primarily for shelter (E. Romero, L. Kaufman, unpublished data). The most productive habitat for the fishery is likely to be one with extensive mangrove forest edges right in the midst of healthy seagrass beds, and also reasonably close to coral reef. The best conditions of this sort exist up and down the Belizean continental shelf behind the barrier reef, and within the lagoons of Turneffe, Lighthouse, and Glovers atolls, with their most perfect expression in the Pelican Cayes and Rhomboid Shoals, between Dangriga and Placencia. The mangrove-seagrass-patch reef mosaic is full of what ecologists call 'ecotones', or places where habitats and species come together, creating high local species diversity. Recent studies reveal that this diversity is considerably higher than anyone had thought, and it is not only a product of those three habitats. In addition to mangrove forests, seagrass meadows, and patch reefs, this region contains large areas of sandy or muddy lagoon bottoms (Mumby and Harborne, 2010). This is a habitat that has previously been ignored except by shrimp trawlers—it is not bright, shallow, or attractive, but it is full of invertebrates that fall prey to commercially important species and support the fishery. Shockingly little is known about this habitat other than that it is still producing species of fishes and invertebrates new to science. Most recently, Philip Lobel discovered what may be a new genus of phoronid, a very primitive worm-like organism related to bryozoans (moss animals) with a beautiful purple filtering apparatus, or lophophore (see Lobel and Lobel, this volume).

In summary, the Belize fisheries are supported by a network of habitats, incompletely known, whose function in fisheries production centers on their interconnections. Not only must there be a sufficient amount of each type of habitat to ensure strong fishery year classes, but they must also be present in a harlequin patchwork that covers the continental shelf, to maximize habitat adjacencies. We are still uncertain of the relative contribution to the grunt-snapper-grouper guild of mainland and inner lagoon mangroves and seagrasses as compared to offshore patches, nearer the barrier reef. However, these nearshore habitats are crucial to species like the lane snapper that are concentrated there, and to inveterate migrators like the goliath grouper, which is highly dependent upon mainland mangroves for its first few years of life (E. Romero and L. Kaufman, unpublished; see also Graham *et al*., 2009)). The entire central region of the Belize MAR—the Pelican Cayes, Rhomboid Shoals, and Gladden Spit—is the largest and best of the mid-shelf habitat mosaics, providing for good growth in all life stages of grunts, snappers, and groupers (Nagelkerken and van der Velde, 2004). This is the area currently under siege by illegal development. Think of it as a commercial and recreational fishery pump, from which random pieces—say, the ignition coil—are being removed before people appreciate that it is necessary for the machine to operate.

In addition to the patchwork-in-place, there also exists a broad-brush habitat zonation between the mainland and outer reef. Inland are the great brackish lagoons and rivers bordered by giant fern and riparian forest of kaway (*Pterocarpus officinalis*), provision tree (*Pachirus aquaticus*), and lowland rainforest species. Approaching the headlands, the riparian forest gives way to mangrove forest, and this continues around the river mouths and along the shore, punctuated by beaches and development. Beyond these, muddy seabottom stretches across the main north-south channel of the lagoon, followed by sandier areas with vast seagrass meadows, and finally the barrier reef. Many young of important fishery species undergoing settlement from the plankton accumulate in seagrass beds near small patch reefs, gathering more and more in the mangrove roots as they get a bit larger. Juveniles of some species range all the way up the rivers and into the inland lagoons, putting on weight before venturing back out onto the continental shelf and the reef. With growth, each cohort spends increasing amounts of time in reefal habitats, finally showing up as subadults on coral reefs, where they are taken by fishers. The pattern is not the same for all species, nor is it etched in stone for any one. Gray (mangrove) snappers reach their greatest abundance and size in the mangroves; lane snappers peak on the inner shelf in seagrass beds and migrate little if at all out to the outer shelf or barrier reef; those seen on the atolls have likely recruited there and settled in the lagoon. Dog, cubera and mutton snappers begin in the mangroves, but are mostly out on the reefs as adults. As juveniles, yellowtails make the least use of mangroves, and most of the seagrass. Once mature, they spend the greater part of their time in fore-reef habitats, feeding above the reef by day on zooplankton, by night haunting the reef and nearby seagrass for crustaceans and fishes (E. Romer, L. Kaufman, unpublished data). Experienced Belizean fishers know each of these species well and they also know that each exhibits a unique life history and behavior.

In their life history diversity, snappers (grunts and groupers show similar patterns) may enjoy a measure of resilience from human-caused changes in the estuarine, continental shelf and coral reef environments. To some extent this may be true of the fish community as a whole. However, each species is also valued in its own right. A commercial fisherman is not overly comforted that it is a great decade for lane snappers (which are small), when it is a horrible one for Nassau groupers (which are larger and worth a great deal more). Conchs do not substitute for lobsters; they are different markets. Overall, the welfare of the fisheries rests upon an intact continental shelf ecosystem, with all of its pieces of adequate size, and located in appropriate places. That is to say, they should look pretty much as they did the last time the entire system was in good health. The Caribbean as a whole is severely overfished, but a reference point set in the 1950s is a modest target, and we are far from it. Were conservation a higher priority, fish biomass would be much higher everywhere and many of the day resting shoals would be composed of large individuals, delivering much greater value than they do now in terms of both fisheries and tourism. Overfishing is reversible, but only as long as the supporting ecosystem is intact. Any threat to the ability of fishery species to progress through their complex life histories, weaving among all of the shelf habitats and drawing what they need from each one, is a threat to the fisheries themselves.

Connections Between Land and Sea

Several species important in Belize fisheries ascend rivers or spend an important part of their lives in estuarine lagoons: certain snappers, tarpons, and snooks among them (Greenfield and Thomerson, 1997). However, what comes down the rivers has the greatest impact on fisheries. Poor land use practices pour sediment into the rivers and ultimately out onto the reef, to ill effect. Rivers also carry toxins, pathogens, and xenobiotics—chemicals from our industrial society that may be highly toxic, or else mimic natural substances and warp the hormonal balance in free living organisms. The greater the basin area and change in altitude within the watershed, the greater the impact of coastwise rivers on the marine ecosystem. Multiply this by the amount of human disturbance in the watershed—paved and deforested areas, dislodged soils, volume of inadequately processed wastes—and you have some idea of the total human impact on coastal waters from the watershed. Reefs at Risk assessed riverine inputs to the MAR by looking at sediment and nutrient loads in all of its effluent rivers. Not surprisingly, the greatest watershed impacts hail from large, mountainous, overpopulated, and largely denuded Honduras. Due to a peculiarity of the oceanography on the Honduran shelf, sediment and pollutants are swept up and displaced westward toward Guatemala and Belize. These pile up against the lower end of the Belizean barrier system, in the Sapodilla Cayes off Punta Gorda (Andrefouet *et al.*, 2002). This is the area in which MMAS surveys identified the highest prevalence of two common and potentially fatal coral diseases—'yellow band' and 'dark spot' (Burton Shank, personal communication). Some coral diseases, such as the 'white band disease' that nearly wiped out staghorn and elkhorn corals in the mid to late 1980s, are pandemics, more responsive to high temperature than to runoff from land. 'Yellow band' and 'dark spot' are more localized in occurrence: the Sapodillas coral disease hotspot seems unlikely to be coincidental. The correlation is consistent with observations elsewhere, and there is a general relationship between runoff from inhabited areas and certain coral diseases. It does not mean that Belize can blame all of its coral disease woes on Honduras. The particular significance of these two diseases is that they attack massive corals, commonly known as 'star' corals (e.g., the three *Montastrea* spp. and *Siderastrea siderea*). *Montastrea faveolata* and *M. annularis* now do the lion's share of building hiding places for fishes since staghorn and elkhorn corals have fallen to a low ebb. This is not good. Massive coral colonies require more than a hundred years to cover significant ground and reach mature size, while habitat construction by staghorn and elkhorn is measured in only one or a few decades. Recovery from WBD can occur in the lifetimes of those now living. Recovery from the toxic and pathogenic effects of runoff from watersheds, or from an offshore petroleum industry, would take centuries.

The Importance of Marine Biodiversity to Coral Reef and Human Health in Belize

Belize is famous for its biodiversity, just as California is for its giant redwood and sequoia trees. U.S. presidential candidate Ronald Reagan's take on redwood conservation in 1966, when people were fighting to keep them all from being cut down (or fighting to cut them down) was "… if you've looked at a hundred thousand acres or so of trees—you know, a tree is a tree, how many more do you need to look at?" His words were famously paraphrased by California Governor Pat Brown as "If you've seen one redwood tree, you've seen them all." Is this true of the marine species diversity of Belize? Can we not afford to lose most of the fishes, or most of the trees, so long as there are still a few around to look at? These are really two questions, one about abundance, and the other about species diversity. The problem with reducing the abundance of fishes and fish habitat in Belize is that their interconnectedness establishes some threshold

of human impact beyond which they will cease to be produced in sufficient numbers to maintain themselves as a coastal marine ecosystem. We do not know where that threshold is for Belize, but MMAS-funded studies in the mid-Pacific demonstrated that it is not very high. In other words, people must tread lightly on marine ecosystems if they care about the things that they provide. The results of all of the recent reef-oriented projects in Belize suggest that we have sailed way past our own threshold: the habitats that support Belizean fisheries are in very serious trouble.

The importance of biodiversity to fisheries is more subtle. Tropical reef ecosystems have existed on earth for more than two billion years, but in long spurts, eventually reestablishing themselves, often in some new form, after extinction events and abrupt changes in sea level or climate. The current epoch of reef growth is about 10,000 years old. During this time, coral reefs have developed around the world that differ greatly in species diversity, yet they are all coral reefs, having done well enough to build large structures and shelter riotous assemblages of brightly colored corals, fishes, algae, and invertebrates. Eastern Pacific reefs have very low diversity; Hawaiian reefs, low; Caribbean reefs, low to medium; Indo-Pacific reefs very high. This is true in the deep past as well; reefs have existed and done perfectly well at many levels of species diversity. However, this indifference to diversity is only true on very large scales of time and space, and without people in the equation.

In today's world, species diversity in coral reef and other marine habitats, matters. Species vary in their tolerances to different stressors, so diversity in species means diversity in function as well. Indo-Pacific reefs have scores of species of fast-growing shallow-water corals. While individual species come and go from any spot, Indo-Pacific reefs have exhibited much greater resilience in recent years than have Caribbean insular reefs. Antillean reefs have only two species of fast growing framework-builders, elkhorn and staghorn coral. Belize and the rest of Central America are blessed with one more fast-growing species, the endemic lettuce coral *Agaricia tenuifolia*. When WBD wiped out the branching corals in Belize, *A. tenuifolia* quickly covered over the shallow reef buttresses and kept them going and viable as good fish habitat. They also kept alive the rich, vibrant, living amphitheatres of world-famous Tunicate Cove and the Pelican Cayes. As described by Aronson *et al.* (this volume), the stay of execution lasted until 1998, when a mass-bleaching event took out both the regenerating staghorn and elkhorn corals, and the disease-resistant, but temperature-sensitive *A. tenuifolia*. Mass-bleaching events and WBD are both tied to anomalously high temperatures, a product of global climate change. Now all three fast-growing corals are making a gradual come-back in Belize. A bit more resilient to high temperatures, and holding the fort on good fishery habitat, are the massive corals. As we have seen, even when able to survive the global phenomenon of thermal stress, the massive corals do fall prey to local watershed impacts; on this scale, the entire Mexico, Belize, Guatemala and Honduras area is local. It is the diversity of forms and physiologies among reef corals that connotes resilience to the community in its entirety. For people, with our short life spans and limited mobility, diversity does matter to the flow of the ecosystem services that we depend upon.

The importance of species diversity is even more apparent for the species we actually go fishing for. Though faring just slightly better than some other spots in the Caribbean, Belize has experienced severe fishing-down, or depletion of its original fishery resources. The fishery held so dear today is a faint, hollow echo of what it was two hundred, or a century, or even just fifty years ago. Nassau grouper, the icon of Caribbean fisheries along with conch and lobster, is actually an endangered species (www.iucnredlist.org/apps/redlist/details/7862/0). So is the goliath grouper, now increasingly threatened by the destruction of mangrove forest (Graham *et al.*, 2009). With the groupers nearly gone, the snappers are king. With cubera down, dog and mutton are eagerly sought after. Even dog has been hard hit. So, to coin a metaphor, 'mutton is bread and butter now'. Large fish have become scarcer, smaller fishes will have to do. A diversity of similar species, i.e., if you've seen one snapper you have definitely not seen them all, has maintained the illusion of a fishery capable of dealing with ever increasing fishing pressure. It can not. Belizeans had actually begun in earnest to catch parrotfishes. Eating parrotfishes is like eating yourself out of house and home. The reef can not function and maintain itself without the parrotfishes. Now that people realize this, we are almost down to the grunts. After that, it would be damselfishes and squirrelfishes. If you want to see what a damselfish feast looks like, go to Jamaica.

The Place of Petroleum in the Fishery's Panoply of Woes

The Belize Department of Fisheries is, like most in the world, full of dedicated people with inadequate resources. The same is true for the government agencies responsible for protecting fish habitats—

essentially, the entire continental shelf of Belize plus the offshore atolls. Belize has one of the most extensive national systems of marine reserves around—13, at last count—and within these are many no-take areas intended to support tourism and replenish the fisheries (Mumby, 2006). These are too few, too small, and by and large, not working due to inadequate enforcement and poor compliance. In a study of fish abundance and fish habitat in the deeper portions of the no-take areas at Half Moon Caye, Laughing Bird Caye and Port Honduras marine reserves, a study led by Burton Shank for MMAS found that only Half Moon Caye exhibited a significant effect of protection: i.e., more fish inside than outside the no-take area. Hol Chan was not included in this study, though it seems to show a strong no-take effect. Also not included were the very shallow waters (<4 m depth) immediately around Laughing Bird Caye, where, on inspection, there appears to be more and larger fishes than anywhere else in the vicinity (personal observation and Lisa Carne, personal communication). That means that in all of Belize, with what on paper appears to be a marvelous network of marine reserves, only three very tiny places show any evidence of real protection. Of course, fishery regulations are in force throughout Belize, and while enforcement is severely resource-limited, without some level of regulation there is little point of even going fishing. So, against this backdrop of overfished stocks, is offshore oil extraction really a serious threat to the fishery?

As we saw in the Gulf of Mexico—twice actually, Ixtoc and Macondo (Deepwater Horizon)—offshore oil fields carry a high risk of something very serious going wrong eventually. Nature is resilient and coral reefs, mangrove forests and seagrass beds are no exception. Occasional petroleum spills, and some very low, but tolerable level of chronic exposure to oil and drilling muds are among the things that they are capable of dealing with, provided that they are in excellent condition to begin with. The Belize fishery estate—the whole, interconnected network of marine habitats and all its inhabitants—is decidedly not in excellent condition. Sixty-five percent of the Belizean reef domain is in poor to critical condition, and it is even worse elsewhere in the MAR (www.healthyreefs.org/eco-health-report-card/2010-report-card.html). This dismal showing is the result of stewardship errors being committed every day from the Maya Mountains to Lighthouse Atoll. Offshore oil development would add yet another blow to the insults whirling about a house of cards. Is the answer to forego offshore oil? Is it to strengthen the house? Or is it both?

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RECONSTRUCTION OF TOTAL MARINE FISHERIES CATCHES FOR BELIZE, 1950-2008[1]

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ABSTRACT

Before the economic impacts of potential oil spills on the fisheries sectors of Belize can be assessed, we need to know more reliably what is at stake. Thus, we need to know how much is actually caught, both at present as well as in the past. Such a baseline cannot be readily provided through officially reported landings data, which are known to be incomplete for most countries. We applied a globally established catch reconstruction approach to the fisheries sectors of Belize to provide a more accurate accounting of total fisheries catches by all sectors back to 1950. This estimate accounts for all fisheries sectors including commercial and non-commercial catches for domestic, tourist and export use. National data and those which are supplied to the Food and Agriculture Organization of the United Nations (FAO) represent mainly catches sold through the fishing cooperatives and those deemed for export. When compared to landings data as presented by the FAO on behalf of Belize, our estimate of total catches were over 3.5 times larger. The FAO and national data report average annual landings of around 2,700 $t \cdot year^{-1}$ since 2000, while our reconstructed total catch estimate averages 6,000 $t \cdot year^{-1}$. This discrepancy was mainly due to unreported catches of sharks, unreported subsistence catches and under-reported catches for the domestic markets and tourism sector. Yet, these sectors contribute substantially to the economic well being of the country. Illegal catch by fishers from neighbouring countries is also a major concern for Belize; however, limited information prevented us from estimating the scope and magnitude of these catches. This study not only highlights the need for improved and holistic accounting of fisheries catches, but clearly illustrated that renewable marine resources are substantially more important for the general economy of Belize than official data would suggest.

INTRODUCTION

Belize, formerly British Honduras, is located on the east coast of Central America between 18˚and 15˚N and 88˚and 89˚W, with a land area of around 22,600 km^2 and an Exclusive Economic Zone (EEZ) of 35,000 km^2 (www.seaaroundus.org; Figure 1). Adjacent to Belize are Mexico to the north, Guatemala to the west and south and the Caribbean Sea to the east. The coastline is flanked by the second longest barrier reef in the world (Heyman and Kjerfve, 2001), beyond which offshore areas drop off to between 300 and 600 fathoms depth. There are several reef areas located offshore, outside of the barrier reef.

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Belize was a British colony from 1862 until gaining partial independence in 1964 and full independence in 1981, and is now part of the British Commonwealth of Nations and a member of the United Nations (Shusterich, 1984). The ethnic composition of the Belizean population consists mainly of Mestizo and Creole, representing approximately 75% of the population, with the remaining 25% consisting of Maya, Garifuna and other ethnicities. A recent census indicated that just under half of the population live in urban centers, which is a decrease from earlier decades (Tietze *et al.*, 2006). Belize has the lowest population density of the Central American countries and one of the lowest population densities in the world, with approximately 9 inhabitants·km^{-2}, Honduras has 49 inhabitants·km^{-2}, and Guatemala has 95 inhabitants·km^{-2} (Heyman and Kjerfve, 2001).

Figure 1. Map of Belize, showing the coastal districts and main coastal cities.

The commercial fishing industry of Belize has traditionally focused on lobster (*Panulurus argus*) and conch (*Strombus gigas*), with the commercial lobster fishery starting in the 1920s (Sheppard, 2000). The establishment of fishing cooperatives in the 1960s greatly improved the sale and marketing of these products for export. Prior to the establishment of the cooperatives, fishing was mainly conducted for subsistence purposes (Craig, 1966; Shusterich, 1984). The cooperatives, however, quickly gained favor and became the major channel for moving fisheries products, mostly to foreign markets. Finfish fisheries have predominantly supplied the local market, although in recent years, export of snapper (Lutjanidae) and grouper (Serranidae) have become more prevalent. A small shrimp fishery also existed, starting in the mid-1960s, with only a few artisanal trawlers and minimal expansion in the subsequent decades (Shusterich, 1984). All trawl fishing was banned in Belize in late 2010, brining this fishery to an end. Sharks, although not consumed locally, are caught for export using mainly gillnets, and supply meat and fins to Guatemala, Honduras, Mexico and Asia (Graham, 2007). It is likely that Belize will enact legislation banning the use of gillnets in the near future, thus substantially limiting shark catches.

The establishment of fishing cooperatives in the 1960s brought about some significant changes to the fishing industry. Most importantly, it allowed fishers to establish a lucrative export market and command a high price for items such as lobster, conch and finfish (Price, 1987). The cooperatives started in the north and expanded throughout the country. Today, there are five main cooperatives (National, Northern, Placencia, San Pedro and Rio Grande), the National and Northern cooperatives being the largest both in numbers of fishers and catches. However, only 50% of licensed fishers belong to one of the five main cooperatives and there are many unlicensed fishers operating in Southern Belize (Anon., 2008a).

In recent decades, Belize has become a popular tourist destination with over 250,000 tourists visiting the country annually (Anon., 2010). The development of the tourism industry was, in part, linked with overfishing, which caused fishers to seek alternate economic activities. Another reason for this shift is the struggle of fishers to make a living due to high fuel costs and lack of capital to maintain equipment and vessels (Anon., 2008a). In the popular tourist areas some of the hotels are actually owned by lobster fishers who used their capital from fishing to start tourism businesses (Price, 1987). Tourism began in the 1980s, and by the 1990s, the industry was well-established. Tourists come to partake in a variety of marine related activities such as diving and sport fishing. During their stay in Belize, tourists commonly enjoy the local cuisine, with a particular taste for Caribbean lobster. This has put further pressure on the marine ecosystem in recent decades (Gillett, 2003).

A survey conducted in the early 1940s by British scientist Ernest Thompson, estimated artisanal and subsistence catches to be approximately three million pounds (1360 t) and one million pounds (454 t), respectively (Thompson, 1944). Thompson (1944) further stated that marine fisheries exports were minimal at that time. Prior to improvements in transportation and processing infrastructure that allowed

for the expansion of commercial production (i.e., lobster and conch fisheries expansion in 1960s), fishing was mainly for subsistence and domestic purposes (Craig, 1966).

Due to a combination of low population density and high reef productivity, it is not surprising that neighboring countries enter Belizean waters to fish. Some of these fishers have special permits to fish in Belize (A. Matura-Shepherd, pers. comm.), while others fish illegally (Heyman, 1996). Depleted fish resources in Honduras and Guatemala have driven fishers to illegally exploit the waters of Belize, which, historically, had less pressure on its marine resources (Heyman and Kjerfve, 2001). The demand for fish products in Guatemala and Honduras increases every year during the Lenten Season, during which Catholics abstain from eating meat (Heyman, 1996). During this time, salted fish (e.g., shark, mackerel, jack and snook) are illegally transported from Belize to Guatemala and Honduras. Other forms of illegal catch from both foreign and local fishers are the harvest of undersized and out of season lobster and conch (Price, 1987; Arce *et al.*, 1997; Perez, 2009).

The goal of this study was to provide a comprehensive estimate of Belizean fisheries catches that includes all fisheries sectors, both commercial and non-commercial, and which accounts for the domestic, foreign and tourist markets. We estimated total marine fisheries catches by Belize over the period 1950-2008 and compared this reconstructed catch estimate to the total landings presented nationally and by the FAO FishStat database. This re-assessment of total marine fisheries catches will help establish a more appropriate baseline of marine extractions in order to monitor future changes and to make more informed management decisions regarding the marine environment and its resources.

METHODS

Population

Human population data were obtained from Populstat (http://www.populstat.org) and from the Statistical Institute of Belize (http://www.statisticsbelize.org.bz/dms20uc/Main.asp) in order to calculate *per capita* subsistence catch rates and domestic market supply. We estimated the coastal urban population for the four main coastal towns and cities (Belize City, Corozal, Dangriga and Punta Gorda; Figure 1), which was then used to derive the *per capita* domestic market supply of fish. To estimate the coastal rural population, we subtracted the urban population of the four main coastal towns from the total coastal population (of the four coastal districts—Corozal, Belize, Stann Creek and Toledo; Figure 1). In the 1950s, a greater proportion of the population lived in the four main urban centers than in the countryside. In the recent time period (2000s), an almost equal proportion of the coastal population resides in these four urban centers as compared to rurally (Figure 2). However, this does not necessarily reflect a migration from urban to rural areas as we only considered these four main urban centers; other communities likely expanded during the time period and sprawl from the main centers likely occurred.

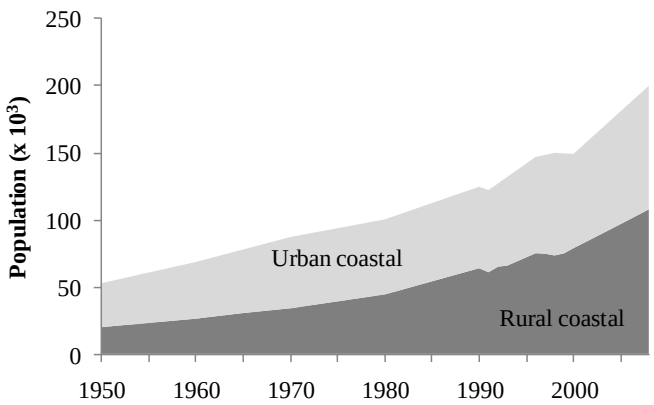

Figure 2. Coastal population in the four coastal districts (Corozal, Belize, Stann Creek and Toledo) of Belize. The urban coastal population in the four main urban centers (i.e., Belize City, Corozal town, Dangriga and Punta Gorda).

Artisanal fishery

The artisanal fishery includes catches for export and for the domestic market. An in-depth look at the data indicated that the reported landings accounted only for catches sold through the fishing cooperatives, which were mainly for export, while the catch by independent fishers for the domestic market was largely un-represented.

Export market

Catches by the artisanal fishers belonging to the fishing cooperatives were, on the whole, accounted for in the national statistics and FAO FishStat data. We compared national catch data to catches presented in the FAO FishStat database and found a close match. Therefore, we concluded good transfer of data between the Belize government (Ministry of Aquaculture and Fisheries) and the FAO. However, these data were only catches from export records and from the fishing cooperatives. From 1950-1976, national landings data accounted only for exported fish and invertebrates, whereas the 1977-2008 time period, they were estimates of total production from fishing cooperatives. In the early time period, the main fisheries products were lobster and conch. While approximately 90% of lobster, conch and shrimp are exported (Anon., 2008a), finfish are mainly caught for domestic consumption (Shusterich, 1984), particularly in the early period, but were poorly reported (Weber, 1968). A small amount of finfish was exported, and in more recent times exports of snapper and grouper increased substantially. From 1977 onward, the national fisheries statistics estimated both exports and total landings of finfish (but only if sold through the fishing cooperatives). Therefore, to estimate under-reported finfish catch between 1950 and 1976, we compared the first few years when national data report both exports and total production (1977-1981), calculated the average difference, and then applied that percentage as an add-on to the 1950-1976 finfish data. This resulted in a cooperative-equivalent 'reported' finfish catch of 136 t for 1950.

For lobster, conch, crab and squid, we used the FAO data as they matched closely the national data. However, in the early period, we assumed that lobster and conch were under-reported, as the national and FAO estimates were low and increased dramatically after the establishment of fishing cooperatives, which was the advent of improved reporting. Therefore, we took a five-year average (lobster: 1959-1963 and conch: 1966-1970) and carried this back to 1950 to account for poor data collection prior to the establishment of the fishing cooperatives.

Domestic market

As the national (hence FAO) data only covered landings sold through the cooperatives (which were mainly exported), we estimated unreported artisanal catches by independent fishers for domestic consumption, sold through the major city fish markets. Thompson (1944) reported that between 3 and 4.5 million pounds (1360-2770 t) of fish were sold in Belize, which we assumed to be the amount of fish sold primarily through the urban markets, as exports were minimal. Using this estimate, we assumed an urban market supply of 1360 t for 1950, from which we subtracted the FAO reported (and early time period adjusted) domestic finfish catch (136 t for 1950, see above) and in combination with the urban population for the four main urban centers, derived a 1950 *per capita* rate for unreported artisanal catches of 37 $kg \cdot person^{-1} \cdot year^{-1}$.

For the early 1990s, Adams (1992) estimated average *per capita* fish consumption for Belize to be 20 $kg \cdot person^{-1} \cdot year^{-1}$. Using this estimate and the human population for 1990, we derived a total domestic demand of 3780 t, which was partially met through subsistence catch (see below). The remaining demand (i.e., 33 $kg \cdot person^{-1} \cdot year^{-1}$) was supplied through artisanal (i.e., small-scale, commercial) fisheries.

In the early 2000s, a data collection program initiated by the Ministry of Agriculture and Fisheries aimed at estimating domestic finfish landings at four of the main landing sites in Belize. With minimal resources available to conduct such a study, estimates were only gathered for a few years. These data were not included in the national fisheries statistics or the data given to the FAO (J. Villanueva, pers. comm., Ministry of Agriculture and Fisheries). These data were, however, presented in a Ministry of Agriculture and Fisheries annual report (2008), which estimated that 649 t of finfish were supplied by Belizean fishers to the four domestic markets in Corozal Town, Dangriga Town, Punta Gorda Town and Belize City. Converted to a *per capita* rate using only the populations of the four main coastal towns and cities, this represents approximately 7 $kg \cdot person^{-1} \cdot year^{-1}$ of artisanal unreported finfish for the domestic market, which was applied to 2008. This is likely an underestimate, given the limited resources available for sampling and the lack of expansion of sample estimates to total market estimate. However, given the scarcity of such data and the fact that finfish remained largely a component of the independent, non-cooperative fisheries catches (i.e., un-reported), we used this estimate as the most comprehensive account of unreported artisanal catches for the recent time period. For all years between the three anchor points used (1950, 1990 and 2008), *per capita* catch rates were interpolated linearly before expansion to unreported artisanal catches using urban human population data. The estimates of unreported artisanal

catches were combined with the reported finfish catches to obtain likely total artisanal fish catches. Note that the reported finfish catches include fish, mainly snapper and grouper, destined for export.

Table 1. Species composition of artisanal finfish catches for Belize, 1950-2008 derived from Heyman and Graham (2000) and J. Villanuva (pers., comm., Belize Fisheries Department).

Common name	Scientific name	Percent of total catch (%)
Yellow tail snapper	*Ocyurus chrysurus*	20.01
Mutton snapper	*Lutjanus analis*	18.02
Lane (or silk) snapper	*Lutjanus synagris*	9.80
Cero mackerel	*Scomberomorous regalis*	8.48
Crevalle jack	*Caranx hippos*	7.28
Great barracuda	*Sphyraena barracuda*	4.34
Grunt	*Haemulon sciurus*	3.24
Cubera snapper	*Lutjanus cyanopterus*	1.07
Dogteeth snapper	*Lutjanus jocu*	1.07
Grey snapper	*Lutjanus griseus*	1.07
Red snapper	*Lutjanus cartagnensis*	1.07
School master	*Lutjanus apodus*	1.07
Common snook	*Centropomus undecimalis*	1.02
Cobia (cabillo)	*Rachycentron canadum*	0.77
Black drummer fish	*Pogonias cromis*	0.77
Lookdown	*Selene vomer*	0.77
Atlantic spade fish	*Chaetodipterus faber*	0.77
Yellow goatfish	*Mulloidichthys martinicus*	0.77
Hogfish	*Lachnolaimus maximus*	0.77
Horse eye jack	*Caranx latus*	0.77
White mullet	*Mugil cephalus*	0.77
Pompano jack	*Alectis ciliaris*	0.77
Saucereye porgy	*Calamus calamus*	0.77
Yellow fin mojarra	*Gerres cinereus*	0.77
Longjaw squirrel fish	*Holocentrus marianus*	0.77
Sea bream	*Archosargus rhomboidalis*	0.77
Goliath grouper	*Epinephelus itajara*	0.67
Spanish mackerel	*Scomberomorus maculatus*	0.57
Jimmy hind	*Epinephelus guttatus*	0.47
Nassau grouper	*Epinephelus striatus*	0.30
Black grouper	*Mycteroperca bonaci*	0.20
King mackerel	*Scomberomorus cavalla*	0.11
Palometa	*Trachinotus goodei*	0.06
Little tunny	*Euthynnus alletteratus*	0.05
Tarpon	*Megalops atlanticus*	0.03
Misc. marine fishes	MMF	10.00

Tourist market

The development of a thriving and highly valuable tourism industry (see Cisneros-Montemayor and Sumaila, this volume), which began in the 1980s, brings thousands of visitors to Belize each year to partake in marine related activities (e.g., diving, sport fishing), including consuming large quantities of seafood, particularly lobster. King (1997) reports that the majority of the lobster served in restaurants of the popular tourist area of Caye Caulker are undersized and illegally harvested. From King (1997), we were able to derive an estimate of the amount of illegally caught, undersized lobster consumed by tourists. King (1997) estimated that 125,000 undersized (<4 ounces or 112 g) lobster were consumed by tourists on Caye Caulker alone in 1990. Assuming a tail weight of 100 g and using a tail weight to whole weight conversion factor of 2, we derived an estimate of 25 $t \cdot year^{-1}$ of undersized lobster consumed by the tourists of Caye Caulker in 1990. We assumed that by 2008, this annual consumption had been halved (12.5 t) due to declining lobster stocks. Using tourism industry data (Anon., 2010), we derived the number of tourist nights per year based on number of hotel rooms and occupancy rates on Caye Caulker, and estimated a per tourist lobster consumption rate of 0.9 $kg \cdot tourist^{-1} \cdot night^{-1}$ for 1990 and 0.14 $kg \cdot tourist^{-1} \cdot night^{-1}$ for 2008. We then expanded our estimate to cover all of Belize using similar information on the number of tourist nights. Tourism in Belize is concentrated along the coast, with the majority of tourists partaking in marine related activities, particularly those associated with the reef (Shusterich, 1984).

Taxonomic breakdown

The main invertebrate species caught by the artisanal sector are lobster (*Panulirus argus*) and conch (*Strombus gigas*), mainly for export. The taxonomic breakdown for the finfish component of the artisanal catch was derived using artisanal fisheries landings data from Heyman and Graham (2000) and a list of targeted finfish provided by the Belize Ministry of Agriculture and Fisheries (J. Villanueva, pers., comm., Ministry of Agriculture and Fisheries). The species composition was applied to both the finfish component of the FAO data and the amount estimated as unreported artisanal catches (Table 1).

Industrial (large-scale, commercial) fishery

While the majority of the fisheries of Belize are small-scale, we considered shrimp catches and tuna catches to be large-scale. Some reports describe the shrimp fishery as being artisanal; however, this fishery deployed trawlers and although catches are relatively low compared to shrimp fisheries in other parts of the world, we consider it to be industrial in scale.

Shrimp trawling started in Belize in 1966 with three trawlers operating in the waters south of Stann Creek (Weber, 1968). By 1988, there were 11 trawlers operating in Victoria Channel and the lagoon between

Placencia and Belize City (McField *et al.*, 1996; Harborne *et al.*, 2000). In the recent decade, the fleet has decreased to only two trawlers (Matura-Shepherd and Stockbridge, 2010), and as of 2010, this trawl fishery has been closed. We compared national shrimp catches to the FAO Fishstat shrimp landings and found an almost perfect match. Therefore, we accepted the FAO Fishstat data as being representative of catches by the shrimp fishery. We applied the species breakdown given by Weber (1968) for the shrimp catch, which was equal proportions of pink shrimp (*Penaeus duorarum*), brown shrimp (*Farfantepenaeus aztecus*) and white shrimp (*P. schmitti*). To estimate discards, we used a shrimp to discarded bycatch ratio of 1:5, given by Allsopp (1980) for the early time period (1966-1978); for the recent time period (2000s), we used a 1:2.5 shrimp to discard ratio from Kelleher (2005). For the period 1978 to 2000, we interpolated linearly between the two rates. We assumed that discarding was greater in the early time period and that any bycatch that was landed was already accounted for in our estimate of subsistence catch (if taken home) or market fish (if sold locally). For the species composition of discards, we used the 1968 FAO study of incidental catch by the shrimp trawl fishery (Weber, 1968). The species composition for incidental catch was mainly silk snapper (*Lutjanus vivanus*), cuskeel (*Lepophridium kallion*) and mojarra (Gerridae), with some assorted flatfish.

The tuna and billfish fishery is a recent development in Belize, with the FAO only reporting catches since 2007. Information on this fishery was limited. Although large pelagic species are plentiful, they are not often caught, as most fishing takes place in inshore waters, in the shallow reef areas (Craig, 1966). Furthermore, the Ministry of Agriculture and Fisheries reports that pelagic species make up less than 1% of finfish caught for the domestic market (Anon., 2008b). Much of the development in the pelagic fisheries associated with Belize is related to foreign owned and foreign operated flag of convenience vessels (Gillett, 2003), and thus are not really Belizean national fisheries. The issue and problematic nature of flag of convenience registries will have to be addressed by the Belize governement.

Subsistence fishery

Catches that did not enter the formal market, i.e., catches either taken home by fishers, or locally traded or bartered, are defined here as subsistence catches. Thompson (1944) estimated subsistence catches to be approximately one million pounds (454 t) in the late 1940s. We assumed that this estimate represented mainly subsistence catches taken by people predominantly living in the major settlements and towns (i.e., what we now call the four main coastal cities and towns: Belize City, Corozal, Dangriga and Punta Gorda). Using the urban coastal population for 1950, we derived an urban subsistence catch rate for 1950. By 1990, we assumed that subsistence fishing in urban areas was much reduced from 1950, and decreased the urban subsistence catch rate to 10% of the 1950 rate (i.e., 1.38 $kg \cdot person^{-1} \cdot year^{-1}$). We held this rate constant from 1990 to 2008.

People living in rural areas likely had limited access to markets, especially in earlier decades. Therefore, their seafood demand was almost entirely met through subsistence fishing. For 1950, we assumed the rural *per capita* consumption rate to be the same as for people living in urban areas. Thus, for the rural areas, the 1950 subsistence catch rate was derived by combining the urban subsistence and domestic unreported artisanal rates (13.8 $kg \cdot person^{-1} \cdot year^{-1}$ and 37 $kg \cdot person^{-1} \cdot year^{-1}$, respectivly) for a rural subsistence catch rate of 50.8 $kg \cdot person^{-1} \cdot year^{-1}$. For recent times, i.e., 2008, we assumed that rural subsistence catch rates had declined to 20% (i.e. 10 $kg \cdot person^{-1} \cdot year^{-1}$) of the 1950 *per capita* rate due to increased availability of other protein sources.

Shark fishery

Although sharks are generally not consumed locally, a shark fishery has existed in Belize since the late 1930s. Thompson (1944) described shark fishing as starting a few years before WWII, targeting predominantly tiger (*Galeocerdo cuvier*) and nurse sharks (*Gyglinostoma cirratum*) for the leather trade, and taking place mainly in the southern part of Belize. National data and FAO FishStat data present shark landings for some years, but catches were low when compared to trade data obtained through the *Sea Around Us* Project trade database (W. Swartz, unpublished data, 2010), which report export amounts of over 1,000 t in some years. Furthermore, Graham (2007) estimated from interviews with shark fishers in Southern Belize that catches were over 800 t in 2006. We took Graham's (2007) estimate as the most comprehensive account of shark catches for Belize in recent times. A recent fisher survey (R. Graham, unpubl. data., Wildlife Conservation Society) suggests that shark abundance has declined since the mid to late 1980s, that sharks captured are smaller and gillnets are the primary culprit. Therefore, we assumed that catches in 1985 were 50% higher than the 800 t reported for 2006 (Graham, 2007) and that the

fishery started in 1937 at zero catches. We interpolated linearly between these anchor points to derive a time series estimate of shark catches from 1950-2006. For 2007 and 2008, we held the 2006 estimate fixed at 800 t. The taxonomic breakdown of shark catches was derived from the detailed account of shark fishing in Southern Belize by Graham (2007), which presents the frequency of elasmobranch landings. The Ministry of Aquaculture and Fisheries provided us with a list of shark species caught in Belize, which was similar to Graham (2007), but also included bull shark (*Carcharhinus leucas*; J. Villanueva, pers. comm., Ministry of Aquaculture and Fisheries). We assumed a catch frequency for bull shark of 5% (by number of sharks) and re-scaled Graham's (2007) frequency distribution to account for the addition of bull shark. To convert catch frequency to catch composition (i.e., percentage of catch tonnage), we obtained weights for each species using length-weight relationship from FishBase (www.fishbase.org). We estimated, for most species, common length as 60% of asymptotic length as presented in FishBase and used the default 'a' and 'b' for all species except *Rhizoprionodon porosus* (Caribbean sharpnose shark), where we used the 'common length' directly. Based on these calculations and Graham's (2007) shark catch frequency, we derived a species breakdown, which we applied to total shark catches throughout the time period (1950-2008; Table 2).

Table 2. Species composition of shark catches in Belize derived from Graham (2007) and J. Villanueva (pers., comm., Belize Fisheries Department).

Common name	Species name	Fraction of total shark catch
Caribbean sharpnose	*Rhizoprionodon porosus*	0.17
Blacktip shark	*Carcharhinus limbatus*	0.06
Great hammerhead	*Sphyrna mokarran*	0.35
Scalloped hammerhead	*Sphyrna lewini*	0.12
Nurse shark	*Ginglymostoma cirratum*	0.15
Bonnethead	*Sphyrna tiburo*	0.01
Lemon shark	*Negaprion brevirostris*	0.03
Bull shark	*Carcharhinus leucas*	0.11

RESULTS

Artisanal fishery

Catches by the artisanal fishery for both foreign and domestic markets, which include conch, lobster, finfish, crab and squid, totaled approximately 200,000 t over the 1950-2008 time period, increasing from 2,260 t·year^{-1} in 1950 to a peak of 4,600 t·year^{-1} in 1984 before declining to 3,200 t·year^{-1} by 2008 (Figure 3). Of this, approximately 100,000 t remained in Belize for domestic consumption by locals and tourists. Lobster catch was over 36,000 t, with at least 12% of this supplying the tourist market. Of the remaining lobster catch, roughly 90% was exported to foreign markets.

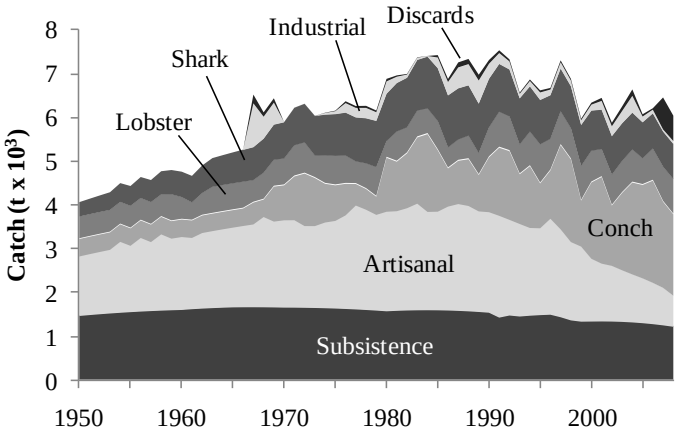

Figure 3. Total reconstructed catch by fisheries sector for Belize, 1950-2008. Artisanal sector represents reported and unreported finfish; Industrial includes shrimp and pelagic fish catches.

Industrial fishery

Shrimp catches for the period 1967-2008 were approximately 2,240 t and discards associated with this fishery were estimated to be 8,700 t (Figure 3). Tuna and billfish catches for 2007 and 2008, the only year of reporting, totalled 1,263 t (Figure 3).

Shark fishery

Estimated total shark catches for the period 1950-2008 were approximately 50,000 t, increasing from 328 t·year^{-1} in 1950 to a peak of 1,200 t·year^{-1} in 1985 before declining to 808 t·year^{-1} by 2008 (Figure 3). We assumed that these were almost entirely exported both for the Asian shark-fin market as well as to neighboring countries for shark meat consumption. Caribbean sharpnose, great hammerhead, scalloped

hammerhead, nurse and bull shark made up nearly 90% of the catch, while blacktip, bonnethead and lemon shark comprised the remaining 10%.

Subsistence fishery

Catches by the informal sector (considered non-commercial) totalled 90,700 t over the 1950-2008 time period, increasing from 1,475 t·year^{-1} in 1950 to a peak of 1,672 t·year^{-1} in the mid 1960s before declining to 1,230 t·year^{-1} by 2008 (Figure 3). The majority of these catches (82%) were from rural coastal areas, while the remainder (18%) was estimated as the subsistence catch taken by the rural coastal population.

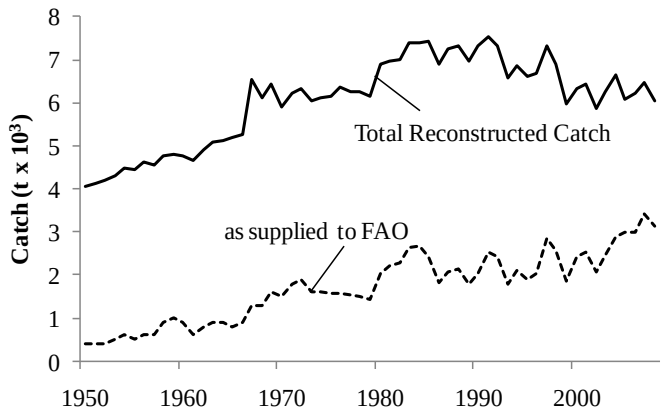

Figure 4. Total reconstructed marine fisheries catch for Belize compared to the total catch as supplied to the FAO by the government of Belize for the period 1950-2008.

Total reconstructed catch

Total marine fisheries catches for Belize, estimated for the period 1950-2008, were approximately 357,000 t, and increased from 4,000 t·year^{-1} in 1950 to a peak of 7,500 t·year^{-1} in 1991 before declining to 6,000 t·year^{-1} by 2008. Our reconstructed catch estimate is 3.5 times larger than the catch total presented by the FAO on behalf of Belize, which was 101,000 t (Figure 4). Conch and lobster comprise almost half of the total catch. In the recent period (2000s), the total reconstructed catch was, on average, 6,200 t·year^{-1}, with approximately 60% being artisanal (including conch, lobster, finfish, etc.), 20% subsistence, 6% industrial and 14% shark (Figure 3). In contrast to the export oriented fisheries for conch and lobster, which show a steady increase or stability in catches (Figure 3), the catches for domestic artisanal and subsistence purposes show a declining trend for recent time periods.

DISCUSSION

Reconstructed catches of marine fisheries for Belize from 1950-2008 totaled approximately 357,000 t. This estimate was over 3.5 times larger than the catches presented by the FAO on behalf of Belize. The main source of this discrepancy was the domestic sector, as catches for domestic consumption by locals and tourist, from both commercial and informal (subsistence) sectors were largely un-represented. This is predominantly due to the system of data collection which relies upon logbooks and records from the fishing cooperatives and trade offices. These only cover a portion of the catch, as independent fishers and non-commercial catches are not accounted for in these reporting systems. Seafood consumption in Belize is not overly high compared to other parts of the world, e.g., the South Pacific (Gillett, 2009). However, lobster is very popular amongst tourists in Belize and finfish is an important protein source for Belizeans. These components that supply the domestic and tourist markets were estimated to be over 200,000 t. Other substantially under-represented fishery components, which were estimated as part of our comprehensive assessment of total catch, were shark fishery catches and discarded bycatch associated with the former shrimp trawl fishery, which together totaled almost 60,000 t.

Of particular concern is the difference in overall signal provided by reported data (dominated by increasing catches of export oriented products) versus domestic supply (dominated by declining domestic catches). This supports the observation made by many Belizeans that fisheries catches are declining, a statement that, until now, had not been supported by any analysis. The discrepancy between the trend in the export oriented lobster/conch fisheries and the domestic finfish fisheries needs addressing through implementation of ecosystem-based management options, including the development of spatial management combining areas open to fishing and full no-take zones, and options for alternative, non-fishing livelihoods to address the potential for substantial excess effort (i.e., number of fishers). The best avenue for such developments lies in improved tourism opportunities and infrastructure for engaging more fishers in tourism ventures.

This study highlights the need for improved data reporting in Belize. The cost of annual monitoring and data collection is often prohibitive, particularly for resource-limited developing countries (Zeller *et al.*, 2007). However, a comprehensive estimate of the catch by the non-commercial sector and by non-registered and non-cooperative fishers, conducted every 4-6 years and interpolated between surveys, would greatly improve the overall accounting of total fisheries extraction by Belize (Zeller *et al.*, 2007).

A recent assessment of the small-scale mutton snapper fishery at Gladden Spit by Graham *et al.* (2008) suggests potential declines in catch per unit of effort (CPUE) and catches of this highly sought-after species. Surveys conducted between 2000 and 2006 indicated a decline in CPUE. While effort was shown to increase, catches seem to be declining. Data from this survey were not used in our estimation of total marine fisheries catches for Belize, as our method of estimating total catch was not able to reflect such a localized decline. However, this study provides strong evidence for over-exploitation of an important domestic fishery, highlighting the need for a more detailed assessment of small-scale fisheries throughout Belize.

Illegal fishing is another issue that needs to be addressed. Territorial disputes over the water's of Southern Belize have encouraged Illegal, Unreported and Unregulated (IUU) fishing. Some licenses have been issued to fishers from neighboring countries, allowing them to fish legally in Belizean waters; however, it is unclear whether these catches are at all reported either by Belize or by the neighboring country. Illegal shrimp trawlers are known to operate in Belizean waters; however, with the legislated ban on shrimp trawling in Belize that came into effect at the end of 2010, illegal trawlers will be more easily identified (Stiles *et al.*, 2010). Shark fishing, also in the southern portion of Belize, has not been adequately recognized in fisheries statistics, and desperately needs better monitoring as shark populations continue to decline globally (Baum *et al.*, 2003). The increased market demand, particularly from Asia, and the high price that shark products command make this a lucrative, but unsustainable industry, and the likely upcoming ban on gillnetting in Belize waters may largely address this issue. The harvest of undersized and out of season lobster is also a concern. The majority of these catches go to the tourist trade, being sold directly to hotels and restaurants without ever being reported as catch. Clearly, enforcement needs improvement, particularly in Southern Belize where much of the illegal shark fishing occurs and where illegal fishers from Guatemala and Honduras come to fish (Anon., 2008a), but also in the north where the majority of lobster trapping occurs.

While there has been a shift in Belize in recent decades from fishing toward tourism, seafood remains an important component of the diet, culture and economy of Belize. Many coastal communities continue to rely on fishing as a source of food and income (Perez, 2009). Coastal development, tourism and climate change all have the potential to alter the marine ecosystem and in turn may impact marine fisheries for which many people in Belize depend upon for their livelihoods. This study provides a baseline of total marine fisheries catches and highlights components of the fishing industry that are currently under-represented in the national statistics. It is hoped that this comprehensive estimate of marine fisheries catches will act as a more appropriate baseline for future management of Belizean fisheries.

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UNDER THE THREAT OF OIL: ASSESSING THE VALUE AND CONTRIBUTION OF BELIZEAN FISHERIES[1]

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ABSTRACT

Belize is host to a rich marine environment, which supports important fishing and highly lucrative tourism industries. However, this rich marine biodiversity and the industries which depend on it are at risk as the Belizean government considers the establishment of an offshore oil industry. Toted as a revenue generator for a stagnating Belizean economy, the potential for loss in fisheries revenue due to an oil spill, highly probably after recent events in the Gulf of Mexico, presents a strong argument for preventing such a development. As was seen recently in the Gulf of Mexico, the potential economic (let alone biological) impact of an oil spill on fisheries alone is substantial. Of significant economic importance to Belize are the Caribbean spiny lobster (*Panulirus argus*) and the queen conch (*Strombus gigas*) fisheries. Both of these fisheries have high market value, are responsible for substantial foreign exchange earnings and create employment both in fishing and processing. The total revenue from Belizean fisheries, including commercial and the generally ignored subsistence sectors, is estimated to be 22 M USD·year^{-1}, with a total economic impact estimated at 65 M USD year^{-1} (in 2011). While the annual revenue generated by fisheries is likely lower than that generated by oil, fisheries are a renewable resource, which provides direct and indirect benefits to the people of Belize in perpetuity. In contrast, oil is a non-renewable resource whose revenue stream is very short-lived in human generational terms. Furthermore, the revenue generated and employment created by the fishing industry plays an important role in the livelihoods, culture and food security of the Belizean people.

INTRODUCTION

Belize has a biologically very rich marine environment, in large part due to its 220 km barrier reef system (see Gibson, this volume), the longest in the Western hemisphere, which runs the length of its coast. The Belize barrier reef complex includes three large atolls, hundreds of mangrove islands, diverse tropical intertidal and subtidal barrier and patch reef zones, and extensive lagoonal seagrass beds (Koltes, 1998). This range of rich and highly diverse ecosystems supports important fishing and tourism industries (see also Cisneros-Montemayor and Sumaila, this volume). These industries rely heavily on the health of the marine environment, from which profound social, economic and biological values abound.

Recent interest in potential offshore oil exploration and exploitation has caused alarm amongst the people of Belize, who are concerned about the risks associated with drilling for oil. Unlike fisheries and tourism, oil is not a renewable resource and has the potential to cause serious adverse effects on the marine environment and associated industries. Stakeholder concern has been mounting since the government has given serious consideration to an offshore oil industry. Making such an important decision regarding the use of a resource requires public access to and knowledge of a proper and full assessment of what is at stake. With the lingering taste of one of the largest oil spills in history, the Belizean government has the chance to learn from the lessons of the BP Deepwater Horizon spill in the Gulf of Mexico in terms of what could go wrong (McCrea-Strub and Pauly, 2011). The lure of potential short-term revenue gained by such an entrepreneurial endeavor may overshadow any serious investigations into the potential long-term losses in revenue, ecological function and social value that could occur if an oil spill were to occur. While we do not speculate on the likelihood of a major spill occurring, it is worthwhile to point out that it was the threat of oil exploration and exploitation that formed the basis for the creation of the Australian Great

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Barrier Reef Marine Park, now a major tourism revenue generator for Australia and a World Heritage Site (Olsson *et al.*, 2008).

Fisheries have long been a part of the livelihoods of the Belizean people, particularly coastal rural communities. The Caribbean spiny lobster (*Panulirus argus*) and the queen conch (*Strombus gigas*) are a main focus of the commercial fisheries sector, bringing in the majority of commercial fisheries revenue. In the 1960s, fishing cooperatives were established, helping fishers negotiate a better price for their lobster and conch catches (Price, 1987; Key, 2002). This had the positive effect of improving the standard of living in fishing villages, creating community solidarity and identity (Key, 2002). A major success of the fishing cooperatives was the establishment of a lucrative export market. Today, most lobsters and conchs are exported to the US and Europe, with a small portion staying in Belize to feed a growing tourist market and for local consumption. The domestic seafood demand is met mainly through reef fish caught by artisanal and subsistence fishers (Anon., 2008). Seafood is an important part of the diet for the coastal population, so in addition to contributing to livelihoods, fishing is also important for national food security.

Economic indicators can be used to assess the value of a fishery, and can also be used to estimate economic losses associated with events such as oil spills (Sumaila *et al.*, in review). The economic indicators used here include total revenue, profit, total economic impact and number of jobs. Total revenue is taken to be the landed value of fisheries catches, i.e., total catch x the ex-vessel prices (the price received by fishers for selling their catch; Sumaila *et al.*, 2007). Profit, a measure of the surplus value after all costs and normal returns have been accounted for, is taken here to be the total revenue less total costs (fixed and variable costs). Fixed costs include the capital cost of fishing vessels/gear, interest and depreciation costs, whereas variable costs include fuel costs, salaries for the crew, repair and maintenance costs (Lam *et al.*, 2010). Total economic impact is calculated by applying an impact (output) multiplier to the total revenue of a fishery to account for additional upstream and downstream impacts such as gear and boat manufacturing and maintenance, the restaurant sector and fuel suppliers (Dyck and Sumaila, 2010; Sumaila *et al.*, in review). The number of jobs associated with the fishing industry can also be used as a measure of the socio-economic value of a fishery as is the possibility of alternate livelihoods.

This report aims to establish a baseline for the contribution of marine fisheries make to the Belizean economy, as a means of assessing the economic risks to the fishing industry from a potential oil spill. The value and contribution of fisheries is estimated using several economic indicators, including total revenue, profit, total economic impact and the number of jobs. Ecological values and social contributions are discussed, as are the potential losses associated with past oil spills in other regions.

Materials and Methods

The contribution of fisheries to the economy of Belize was estimated by calculating the total revenue, profit, level of employment and total economic impact of fisheries (e.g., Sumaila *et al.*, 2007; Dyck and Sumaila, 2010; Lam *et al.*, 2011). These economic indicators were estimated separately for the various fisheries sub-sectors, including the commercial fisheries for export and the domestic market, and the subsistence fisheries sectors. Although an important recreational fisheries sector exists in Belize, due to its close association with the tourism sector, recreational fisheries were not included in this assessment. Here, we focus only on commercial and subsistence fisheries (but see Cisneros-Montemayor and Sumaila, this volume). As the present economic valuation is founded on catch data, we use here the estimates of reconstructed total catches (Zeller *et al.*, this volume), rather than landings data reported by the Belize government, which are known to be incomplete. This ensures a more comprehensive assessment of the value and economic contribution of fisheries.

Total revenue

We derive total revenue as the landed catch volume multiplied by the ex-vessel price (see Appendix). Fisheries in Belize are mainly small in scale, supply domestic and foreign markets, and have both commercial and non-commercial components. The commercial fishery is comprised of small vessels including open boats, sail sloops and canoes (Perez, 2001). The number of registered vessels is estimated at approximately 800; however, it is known that there are many unregistered vessels in operation. In the early 2000s, the number of licensed fishers was estimated to be 2,662 (Perez, 2001), while over 3,500 people are thought to be employed by the industry (fishing and processing) in 2002 (Tietze *et al.*, 2006). Estimates for the number of unregistered commercial fishers, and the number of people engaged in subsistence fishing were not available. Approximately 75% of registered commercial fishers belong to one

of the five Fisherman's Cooperatives (National, Northern, Placencia, Rio Grande and Caribena; Perez, 2001). The majority of commercial catches are processed through these cooperatives, with some exported and some sold locally. Catch sold directly by fishers to local markets, resorts and restaurants are rarely accounted for in the official statistics (Huitric, 2005; McField and Bood, 2007), and neither are catches from the non-commercial or subsistence sector. To estimate total revenue, catches were separated into those for the commercial export and domestic markets, and the non-commercial (subsistence) sector, and are based on historic catch reconstruction research (Zeller *et al.*, this volume).

Export market

Total revenue from exports was estimated using export quantities and prices. Approximately 8% of export earnings in Belize are from marine products (Anon., 2009). Lobster and conch are particularly important export items, accounting for half of marine export earnings. However, reef fish and shrimp also contribute to export earnings. National fisheries export data were obtained from the Belize Ministry of Fisheries and Agriculture for the year 2008, which included export numbers and values (J. Villanueva, personal communication, Ministry of Agriculture and Fisheries). These were comparable to trade data obtained from the *Sea Around Us* Project trade database (W. Swartz, pers. comm., University of British Columbia's Fisheries Centre).

Based on national production and export data, lobster exports represented 90% of total commercial lobster landings, and are estimated to be 193 t (tail weight) with an export price of around 36 USD·kg^{-1} (Anon., 2008). Conch is the second major target species of Belizean commercial fisheries with much of the commercial catch going to foreign markets. Based on government trade data, 240 t of conch meat and fillets was exported, which represents 1,675 t live weight. The Food and Agriculture Organization of the United Nation's (FAO), on behalf of the Belizean government reports 1,861 t of conch (whole live weight); therefore, the difference (186 t) was assumed to be retained for the domestic market. The export revenue from lobster, conch, finfish, shrimp and shark was calculated from the quantity of exported item combined with the export price (Table 1).

Table 1. Lobster and conch volume (t) and prices for export, domestic and tourist markets. Prices converted to 2011 USD using the Belize Consumer Price Index (IMF, 2010).

	Amount (t)	Type	Price (USD·kg^{-1})
Lobster			
Export	193	Tail	36.00
Domestic	64	Whole	8.00
Tourist	152	Whole	12.00
Conch			
Export	240	Market clean	13.00
Domestic	26	Market clean	7.00

Domestic commercial market

Total revenue from catches supplying the domestic market was estimated using dockside (i.e., ex-vessel) prices in combination with total catches (export component excluded). Current dockside prices in Belizean Dollars (BZD) per pound were obtained for many commonly caught fish and invertebrates (R. Graham, personal communication, Wildlife Conservation Society). Prices were converted to USD per kg using 2011 currency exchange rates (March 2011; www.oanda.com/currency/converter). For some species of minor commercial interest, dockside prices were not available. To estimate a price for these species, the average price for species of minor economic interest (mostly reef-fish, but with highly valued snapper and grouper excluded) was used as a proxy for these fish. Prices listed in product weight (e.g., lobster or shrimp tails, or market clean conch) were converted to whole weight (wet- or live weight) equivalents using FAO conversion factors (FAO, 2011). Prices in 2011 USD were then applied to the most recent available catch data (year 2008, based on Zeller *et al.*, this volume). We assumed catches in 2011 to be similar to those in 2008.

To determine the portion of the catch retained domestically for species supplying both markets, exported product amounts were converted to whole weight equivalents. Lobster, conch, finfish and shrimp were converted to whole weight using conversion factors of 3.0 (M. Gongora, pers. comm., Ministry of Agriculture and Fisheries), 7.0, 2.0 and 1.6, respectively (FAO, 2011). Dried shark as presented in national export records were considered to be dried fins, which were converted to whole weight using a 1.44% fin to body ratio (Graham, 2007). For example, the amount of lobster sold or consumed domestically was estimated to be 64 t, based on subtracting exports from the reconstructed total lobster catch (Zeller *et al.*, this volume). Lobster caught for direct sale to tourists (e.g., resorts), represented another 152 t of whole

lobster. Lobster consumed by tourists is not accounted for in the official fisheries catch statistics, but was estimated by Zeller *et al.* (this volume) using tourist numbers and estimates of lobster consumption by tourists. Undersized lobster is often caught and sold directly to resorts, without being reported or accounted for. These catches, however, generate a valuable source of revenue and are therefore included in the present economic assessment.

To derive total revenue from domestic market sales, dockside prices in 2011 USD were applied to total domestic market catches in 2008 as expressed in equation (1):

$$R_D = P_D * C_D \quad \text{... 1)}$$

where R_D represents total revenue from sales to the domestic market, P_D is the ex-vessel or dockside price, and C_D is total catch sold domestically.

Non-commercial (subsistence)

The reconstructed catch estimates used for this study (Zeller *et al.*, this volume), distinguish non-commercial from commercial fisheries, where the former is designated as the subsistence sector, which plays an important role in providing food, particularly to rural coastal communities. Some fishing villages retain almost all of their catch to feed their families and community while in other villages the most valuable fish are sold and the rest is retained for home consumption (Gibson *et al.*, 2005). The subsistence sector therefore plays a key role in contributing to national food security. Of the total estimated catch in 2008, approximately 20% was derived from subsistence fisheries (Zeller *et al.*, this volume). In order to value this sector, a 'shadow' price, equivalent to the dockside (R. Graham, personal communication, Wildlife Conservation Society) price, was used to estimate the total revenue equivalent of this sector.

Profit

To determine profit, total cost was estimated using data obtained from a global cost of fishing database (Lam *et al.*, 2011) and subtracted from each revenue item. Fishing cost data are presented in the database as cost by gear, country and year. To calculate total cost, each species was assigned a gear-type based on available data (Heyman and Graham, 2000; McConney *et al.*, 2003; Graham, 2007). The main fishing gears are traps for targeting lobster, free divers (by hand and spear) to capture conch, handline and gillnet for reef and demersal fish species, and trawls for catching shrimp[2]. Fishing cost data obtained from the database in USD per tonne of catch (real 2005 USD) were converted to 2011 USD using the consumer price index (CPI) for Belize (IMF, 2010). Catches by gear were then assigned a cost per tonne of catch, using fixed (capital, interest and depreciation) and variable (fuel, running and repair costs and labor) costs (Lam *et al.*, 2010).

Profit for the year 2008 was then derived by subtracting total cost (C_T) from total revenue, being domestic revenue (R_D) plus export value (E), equation (2). Total revenue was taken as the revenue from the commercial (domestic and export markets) and subsistence sector. Because the majority of the commercial sector is small-scale, with catches taken mainly by hand, costs were assumed to be similar for the non-commercial sector. Thus profit is expressed as:

$$\text{Profit} = (R_D + E) - C_T \quad \text{... 2)}$$

Economic impact

The economic benefits from the fishing industry can be both direct and indirect. The higher price for exported products account, in part, for some of the value added through processing. The indirect benefits of the commercial sector were estimated using an output multiplier applied to the landed value of the catch retained domestically and the export value for the catch going to foreign markets. Output multipliers are one way to account for the economic activity derived through the various secondary linkages to the fishing industry. These secondary benefits were calculated using an impact multiplier of 3.46 based on work by Dyck and Sumaila (2010), which accounts for the direct, indirect and induced effects of fishing. The multiplier accounts (at least partially) for upstream and downstream impacts of fishing such as boat

[2] Shrimp trawling has been banned since in Belizean waters (Matura-Shepherd and Stockbridge, 2010)

building and maintenance, gear manufacturing, and the restaurant sector (Dyck and Sumaila, 2010). Using this multiplier, the economic impact was calculated using the price (ex-vessel or export price) and amount of catch, equation (3). The impact multiplier was applied only to the commercial sector. Subsistence fisheries have much fewer associated secondary benefits, as the fish caught by this sector are generally for personal consumption, thus resulting in a short value chain (Dyck and Sumaila, 2010).

$$I_E = R_c \cdot x \cdot m + R_s \qquad \ldots 3)$$

Where I_E is the total economic impact, R_c is the total revenue from the commercial sector (domestic and export markets), m is the impact multiplier and R_s is the revenue equivalent from subsistence fisheries.

RESULTS

Total revenue from the fisheries sector is estimated to be 22 M USD in 2011 (Table 2). This included 6.7 M USD in direct revenue from catches for the domestic market, 10.6 M USD in export revenue, and 4.7 M USD for the subsistence sector. Export earnings for lobster were estimated to be 7.6 M USD, while lobster for the domestic market had revenues of 500,000 USD. Export of conch generated 3.0 M USD in revenue, while domestic conch sales were estimated to be 193,000 USD.

Table 2. Economic impact (Year 2011 M USD) of fisheries in Belize, including direct revenue and indirect economic contributions from the various sub-sectors.

Sector	Revenue	Indirect Impact[b]	Total Impact
Commercial (domestic[a])	6.7	16.4	23.0
Commercial (export)	10.6	26.2	36.8
Subsistence	4.7	n/a	4.7
Total	22.0	42.6	64.5

[a] includes tourist market; [b] Impact multiplier of 3.46 (Dyck and Sumaila, 2010) applied to all sectors except subsistence.

Total cost of fishing in 2011 was estimated to be 8.6 M USD. Profit from the fishing industry was estimated to be 13.5 M USD, based on total estimated revenues of 22 M USD, estimated fixed costs of 1.6 M USD and variable costs of approximately 7.0 M USD.

The total economic impact of all fisheries sectors combined was estimated to be approximately 65 M USD, of which 42.6 M USD accounted for indirect benefits derived from fishing (Table 2). Direct employment from the commercial fishing sector was estimated to be roughly 3,000 people. It was not possible in the present study to calculate additional jobs created through indirect and induced channels as a result of the fishing industry, but these are likely substantial.

DISCUSSION AND CONCLUSIONS

Total revenue from fisheries in Belize was estimated in this study to be 22 M year 2011 USD (44 M BZD) with an estimated total economic impact of 65 M USD. While the most recent year of available catch data was 2008, we assumed similar catches for 2011. Combining these catches with current prices, we calculated total revenue, profit and economic impact in 2011 values. Profit from the commercial fisheries sector was estimated to be 13.5 M USD. Employment generated by the commercial fisheries sector was estimated in the 2000s to be almost 3,000 jobs. However, a Ministry of Agriculture and Fisheries report (Anon., 2008) indicated that 15,000 Belizeans benefited from fishing activities in 2008. The Statistical Institute of Belize estimated the employed population in 2009 to be over 120,000 people, which suggests that up to 12% of the working population are employed either directly or indirectly by the fishing industry. Unemployment rates in 2009 were estimated at 12.6% (Anon., 2010) and may have increased since then. Alternate livelihoods are limited for fishers in many communities. Some fishers have successfully transitioned from fishing to tourism; however, in the case of an environmental disaster affecting the marine environment, tourism as an alternative livelihood might not be an option. Subsistence fisheries represented almost 20% of the total catch, and based on a shadow price estimate, were valued at 4.7 M USD. Subsistence fisheries in many remote coastal villages provide a primary source of protein and therefore contribute significantly to national food security (Gibson *et al.*, 2005). However, this fisheries component is often overlooked both in fisheries statistics (Zeller *et al.*, 2007) and economic evaluations (Zeller *et al.*, 2006).

An assessment of the economic contribution of coral reef and mangrove fisheries in Belize (Cooper *et al.*, 2009) estimated that total revenue from the fishing industry (recreational sector excluded) was between 14.2 and 15.9 M USD in 2007. However, the methodology used was very conservative, particularly in

estimating local sales. Both Cooper *et al.* (2009) and our estimate were similar for export sales as these were based on well-documented export and fishing cooperative records. Furthermore, our estimate of overall impact was greater due to the use of a higher multiplier for estimating indirect impacts from the fishing industry. The impact multiplier used in this assessment was based on work done by the Fisheries Economic Research Unit (FERU) at the University of British Columbia (Dyck and Sumaila, 2010), which calculated output multipliers specifically for the commercial fishing industry. The multiplier used in Cooper *et al.* (2009) was based on a conservative estimate from tourism and recreational sectors in other countries (Fedler, 2008). Although considerable uncertainty can exist in developing and applying multipliers, total economic impact is a useful indicator of the importance of this industry to the overall economy. Future improvements to the use of multipliers as an indicator would require the collection of extensive data and the development of a Belize-specific input-output model.

Commercial fisheries in Belize are thought to be relatively well managed; however, poor monitoring of some sectors, the increase in illegal fishing and the use of destructive gears such as gillnets all pose threats to long-term fishing potential and may already be causing declines in catch (Heyman and Graham, 2000). While overfishing is currently not as much of a concern as in other parts of the Caribbean (McField and Bood, 2007), if fisheries are not properly managed, their long-term benefits to society and the economy will be compromised. Management strategies, which would secure future benefits include setting and enforcing appropriate quotas to avoid over-fishing, establishing and maintaining no-take marine protected areas to allow for natural stock regeneration and spill-over, adequate enforcement to prevent illegal fishing and restrictions on gears that are destructive or have un-necessarily high bycatch. From an economic stand point, more benefit could accrue from value-adding to products through the processing and marketing of species, which have traditionally been of lower value (Heyman and Graham, 2000). The invasive lionfish, for example, could be marketed and sold as both a way to alleviate damage to reefs and ease the pressure on threatened grouper and snapper species (R. Graham, personal communication, Wildlife Conservation Society).

Beside the potential for overfishing, the marine ecosystems of Belize are also under the threat of oil. Proposals for a domestic marine oil industry must be weighed against the real threat of pollution damages associated with this industry. The inevitable seepage of oil and sediment contamination due to drilling fluids threaten the health of the Belizean coast. In addition, the possibility of oil spills (both chronic and catastrophic) puts the ecosystem at risk, and has the potential to cause serious losses in the value of the fisheries, which depend on healthy reef and mangrove ecosystems. Oil pollution damages both public natural resources and private property (Boyd, 2010). Fish are public property, as are mineral resources such as oil. The decisions on how these resources are best used (or not) should also be in the public domain, as the economic, social and biological impacts of use (and misuse) span widely across society.

Assessing natural resource damages in terms of economic consequences can be challenging (Boyd, 2010). Such an assessment requires a profound understanding of the biophysical system in which the damaged resource is derived. Baseline studies and an in-depth knowledge of the interplay between fisheries (i.e., humans) and the marine ecosystem is fundamental to understanding what is at risk and what could be lost if an oil spill were to occur. Drawing upon previous post-spill analyses, including the *Exxon Valdez* oil spill in Prince William Sound, Alaska (Peterson *et al.*, 2003), the *Prestige* oil spill off the Galician coast in Spain (Garza-Gil *et al.*, 2006; Loureiro *et al.*, 2006), the wreck of the *Witwater* near Galeta Marine Laboratory, Panama (Jackson *et al.*, 1989) and the recent Deepwater Horizon oil spill in the Gulf of Mexico (McCrea-Strub *et al.*, 2011; McCrea-Strub and Pauly, 2011), the impacts of oil spills have been shown to be substantial and long-lasting. From a biological point of view, ecological processes are disrupted, mortality of sensitive species occurs and there is long-term degradation of ecosystem health and services. Economically, there can be substantial losses in fisheries revenue, profits and jobs. Social impacts may be more subtle, but include increased tension and anxiety amongst fishers, and loss of morale as fishers struggle to find alternative sources of income.

The recent explosion of the BP Deepwater Horizon rig in the Gulf of Mexico—a major environmental catastrophe—has had only a preliminary assessment of economic losses (McCrea-Strub and Pauly, 2011; McCrea-Strub *et al.*, 2011; Sumaila *et al.*, in review). However, the preliminary assessment has shown substantial losses in revenue, profits, wages and jobs (Sumaila *et al.*, in review). As time passes and the longer-term effects are factored in, including lost opportunity costs over time, this estimate may actually be significantly higher. It could be argued that a similar oil spill in Belizean waters might have much greater environmental impacts, given that the coastline is almost entirely comprised of mangroves,

seagrass beds and shallow reefs—all of which have a high sensitivity to oil exposure (Nansingh and Jurawan, 1999). In terms of potential economic losses, the main fisheries—lobster and conch—would almost certainly be affected as would the reef fisheries that supply local markets. Potential impacts on the recreational fisheries and tourism sector (Cisneros-Montemayor and Sumaila, this volume) could also be quite substantial as most of the popular and valuable sports fisheries take place in the mouths of rivers, estuaries and lagoons.

Even more difficult to estimate, but likely very substantial, will be the losses in tourism attractiveness if Belize's marine environment becomes tainted by the existence of or threat from oil exploration and exploitation. Based on the economic assessment presented here for the fisheries of Belize, the sensitivity of the Belize marine environment and the losses observed from other historic oil spills, it is argued that the potential losses if an oil spill were to occur in the water's of Belize would be substantial. If managed sustainably, fisheries are a perpetually renewable resource. Oil is not. The present value of total economic impacts from fishing over a 50 year time period using a discount rate of 3% would be upwards of 1.7 B USD[3]. While the revenue derived from oil may exceed that from tourism and fisheries in the short-term, oil is a non-renewable resource and lacks the sustainable future that both tourism and fisheries industries provide. Equally significant is the fact that while the majority of revenue and profit of fisheries remain within Belize (i.e., accrue to the people of Belize), the majority of revenue and profit from oil exploration would go overseas to accrue with the international stakeholders of the oil companies. In summary, the short-term economic and political allure of oil resource revenue must be balanced with the long-term view of sustaining the livelihoods of the Belizean people into the future. Even if oil deposits last for 50 years, the loss in fisheries and tourism revenue over the long term may be much more costly to the Belizean people than the finite benefits accrued through marine oil extraction.

ACKNOWLEDGMENTS

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[3] Prevent value of economic impacts through time were estimated using: , where T= 100 years; d= discount factor; and X= total annual economic impact (see Results).

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APPENDIX

Ex-vessel and export prices for Belizean fisheries catches.

Taxon Name	Dockside price (USD/kg whole weight) [a]	Export price (USD/kg product weight)
Atlantic spadefish	2.90	-
Black drum	2.90	-
Black Grouper	4.20	-
Black stone crab	6.00	-
Blacktip shark	3.00	-
Bluestriped grunt	2.40	-
Bonnethead	3.00	-
Brown shrimp	6.00	-
Bull shark	3.00	1.50
Caribbean sharpnose shark	3.00	1.50
Caribbean spiny lobster	8.30	35.99
Cero Mackerel	3.60	-
Cobia (Cabillo)	3.60	-
Common snook	6.00	-
Crevalle jack	2.40	-
Cubera snapper	4.20	-
Dog snapper	4.80	-
Goliath grouper	4.20	-
Great Barracuda	3.60	-
Great hammerhead	3.00	1.50
Great pompano	2.90	-
Grey snapper	4.80	-
Hog fish	4.80	-
Horse-eye jack	2.90	-
Jimmy hind	3.00	-
King mackerel	3.60	-
Lane snapper (silk)	4.80	-
Lemon shark	3.00	1.50
Longjaw squirrelfish	2.90	-
Lookdown	2.90	-
Miscellaneous marine fishes	2.80	-
Mutton snapper	4.80	-
Nassau grouper	6.00	-
Nurse shark	3.00	1.50
Pink conch	1.00	12.6
Pink shrimp	6.00	9.5
Pompano jack	2.90	-
Red snapper	4.20	-
Saucereye porgy	2.40	-
Scalloped hammerhead	3.00	1.5
Schoolmaster snapper	4.20	-
Sea Bream	2.90	-
Southern white shrimp	6.00	-
Spanish mackerel	3.60	-
Tarpon	1.70	-
Tourist lobster	11.90	-
White Mullet	2.90	-
Yellow fin mojarra	1.80	-
Yellow goatfish	2.90	-
Yellow tail snapper	4.20	-

[a] Dockside prices in 2011 BZD/lb converted to USD/kg using currency exchange rate in March 2011, except for Atlantic spadefish and Black drum whose prices are from the average for minor commercial reef fishes.

THE ECONOMIC VALUE AND POTENTIAL THREATS TO MARINE ECOTOURISM IN BELIZE[1]

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ABSTRACT

Tourism is one of the most important industries in Belize, contributing around 20% of yearly GDP, and marine ecotourism is a particularly important and rapidly expanding sector. With this in mind, we analyze the current state of marine ecotourism in Belize, compiling information on the various activities that take place, providing an estimate of the yearly economic benefits that they generate. Our results suggest that each year, almost 160,000 participants in marine ecotourism generate over 128 million USD that in turn supports around 4 thousand jobs. Marine ecotourism includes recreational fishing, dedicated shark and whale watching, and diving and snorkelling at beaches and reefs. All of these activities contribute to the coastal economy and strengthen the image of Belize as an attractive tourist destination, while being economically and environmentally more sustainable that resource extraction. Marine ecotourism directly depends on the health of marine ecosystems, and on the perception that potential tourists have of the sites. We use case studies from other parts of the world to identify potential economic losses stemming from a large-scale environmental disaster, in this case a hypothetical oil spill, in Belizean waters, providing an estimate of losses over time.

INTRODUCTION

Tourism is evidently one of the most important industries in Belize, contributing around 20% of yearly GDP. Accordingly, there have been concerted efforts to improve tourism management in the country, both by government and non-governmental organizations. In the case of ecotourism, this has involved monitoring and enforcement efforts, as well as attempts to gauge the results of protected areas for local livelihoods. An important part of these efforts has been to shift tourism away from traditional 'mass-consumption' sites towards smaller-scale, community based ecotourism initiatives that promote the conservation of nature, yet can still provide economic and social benefits to mitigate the effects of restricted access to traditional resources (Lindberg *et al.*, 1996; Belsky, 1999).

Marine ecotourism is a rapidly expanding sector, with millions of international and domestic participants worldwide (Cisneros-Montemayor and Sumaila, 2010). 'Marine ecotourism' (MET) here refers to any activity that takes place in the marine environment and depends on marine life. This includes recreational fishing, whale watching, shark watching, scuba diving and snorkeling (but not swimming or kitesurfing). As with any industry that depends directly on the status of the marine environment, investing in conservation and protection of marine resources and their habitat will help ensure that benefits from MET increase and are sustained over time (this includes minimizing potential impacts of tourists themselves; Farrell and Marion, 2001). In addition to infrastructure or marketing, these investments also include conservation measures such as marine protected areas or the promotion of tourism operator participation in management plans, monitoring, and enforcement of conservation measures.

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In this work, we attempt to estimate the socioeconomic importance of MET in Belize. Our goal is to establish an economic baseline of benefits that can be improved upon and used as a benchmark for future studies or for cost-benefit analyses of competing industries in Belize and other countries.

METHODS

Data on current status and trends of MET in Belize were compiled from sources including peer-reviewed literature, government and NGO reports and newspaper articles. Our main performance metrics were expenditures, employment and participation in marine ecotourism. Expenditures refer to money spent on activities directly related to MET, such as ticket fees, accommodation, lodging and transport costs. Expenditures were converted to 2011 USD using the official US inflation rate (www.bls.gov).

When tourist operators use these expenditures to purchase other goods and services, total economic value is increased as spending moves through the economy and employment is generated throughout the process. The ratio of expenditures to total economic value is termed an economic multiplier. For instances in which we had expenditures, but not total economic value, we used multipliers reported by Fedler (2008) in a study of Belizean sport fishing. It is important to note that our estimates refer strictly to actual money spent on marine ecotourism activities, not the non-use value of the marine ecosystem, so our estimates clearly underestimate total economic value.

To contextualize the contribution of marine ecotourism to Belize, we calculated an index of relative importance of marine ecotourism for the Central America FAO subregion (www.fao.org, which includes Mexico). This index is calculated for each country as the average of three components: marine ecotourism participation weighted by total tourist arrivals, tourist expenditures weighted by country GDP, and marine ecotourism employment weighted by the total population. The resulting weighted averages are then rescaled relative to the highest-ranked country. In this way, we attempt to control for the large socioeconomic differences between countries in the region. For example, MET in Mexico generates very high expenditures, but that country's GDP and population are also much larger than others in the Central America FAO subregion.

The potential effects of a large-scale environmental impact such as an oil spill on Belize were explored using information gathered from articles and reports that analyzed the economic impact of oil-spill sites around the world, including Alaska and Massachusetts (US), the Brittany coast (France), and Panama (Teal and Howart, 1984; Jackson *et al.*, 1989; Anonymous, 1990; Anonymous, 1993; Peterson *et al.*, 2003; Culbertson, 2007; Culbertson *et al.*, 2008). These reports suggest an average of three years for tourism activities to return to pre-spill levels, but environmental effects can continue to hinder marine tourism due to lingering ecosystem impacts that result in poor conditions for recreational fishing or scuba diving. In the case of marshes and reef ecosystems such as those in Belize, such effects involve mortality or displacement of marine life to anywhere between 20-100% of initial conditions, depending on the type of organism (for example, fast-swimming fish recover more quickly than mangroves or coral reefs), with visible effects lasting about 10 years. Because we do not have data available for a breakdown into particular species groups, we assume a very conservative first-year reduction of 70% in overall marine ecotourism due to site perception, returning to pre-spill conditions after 3 years. In addition, we assume a further 50% reduction in tourism due to environmental degradation, returning to pre-spill conditions after 20 years. To keep this calculation simple, we assume a linear recovery pattern for both cases and a constant discount rate of 3% per year.

RESULTS AND DISCUSSION

Marine ecotourism contributes significantly to the Belizean economy, both in absolute and relative terms. Our estimates suggest that each year, about 160,000 people participate in these activities, generating over 128 M USD and supporting almost 4,000 jobs (Table 1). Employment

includes indirect jobs for recreational fishing and diving and snorkeling, but only direct jobs for shark and whale watching, and so is an underestimation. Nevertheless, the importance of MET in Belize cannot be overstated. In order to gauge the socioeconomic contribution of the MET industry to the country, we calculated an index using the number of participants, expenditures and employment in these activities, weighted by total tourism, country GDP and total population, respectively (see Methods).

Table 1. Yearly participation, expenditures and economic impact in marine ecotourism in Belize, by activity.

Activity	Number of Participants	Total Expenditures (2011 USD)	Total Economic Impact (2011 USD)	Employment
Recreational fishing	5,800	27,245,000	61,219,840	1,860
Diving and snorkeling	150,000	37,053,000	57,395,100	1,900
Shark watching	2,010	6,015,000	9,317,240	154
Whale watching	370	203,600	315,380	4
Total	158,180	70,516,600	128,247,560	3,918

Belize ranks the highest out of all countries in Central America in terms of the socioeconomic importance of marine tourism, rivaled only by Costa Rica (Figure 1). This highlights the need for proper management and protection of the marine ecosystem; national and foreign tourists clearly value a clean and attractive ecosystem, and can switch to other sites if an ecosystem is degraded. An important point to keep in mind is that, with a growing suite of ecotourism options, the mere perception of ecosystem damage can often impact tourism negatively.

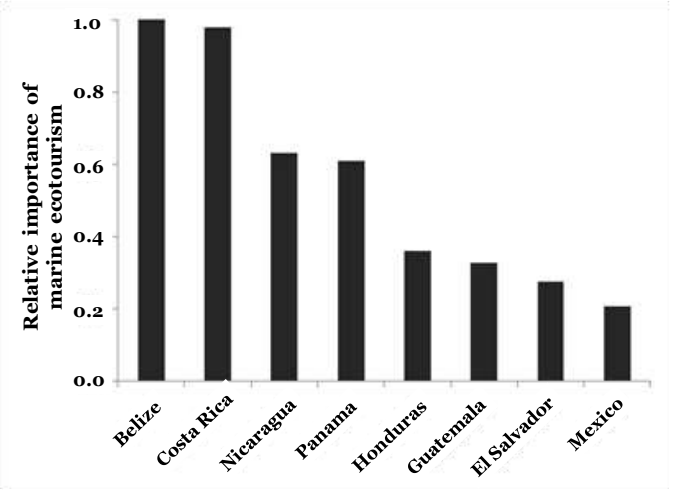

Figure 1. Relative importance of marine ecotourism for countries in the Central America FAO subregion. Index is the average of marine ecotourism participation weighted by total tourist arrivals, tourist expenditures weighted by country GDP, and marine ecotourism employment weighted by the total population. Values are scaled relative to the highest-ranked country.

Along with most of the world, the growing popularity of ecotourism in general, and marine ecotourism in particular, has resulted in increased participation and expenditure at a number of sites. Belize is a clear example of how sound environmental and tourism management, combined with good marketing plans, can result in stable local benefits (Kangas *et al.*, 1995). Accordingly, Belize has quickly grown into a world renowned site for shark watching, particularly focusing on whale sharks (Cohun, 2005). In the decade between 1997 and 2008, visitors at Gladden Spit increased from 70 to 2,000, while expenditures increased from 280,000 to over 6 M USD (Carne, 2008). Along with participation, employment in this activity has also grown steadily (Figure 2), though there are some concerns about overcrowding of the sites, or potential impacts on whale sharks due to diving pressure and propellers in the area (Roberts and Graham, 2003). These concerns must be addressed quickly, as the aggregation patterns that make whale sharks amenable for tourism can also make them more susceptible to local human impacts.

Whale watching has been a growing industry throughout the world, and has been documented globally for over two decades (Hoyt, 2001; Hoyt and Iñiguez, 2008; O'Connor *et al.*, 2009). The results of these reports for Belize for 1991-1998 and 2008, as well as an estimation for 2003 (Cisneros-Montemayor and Sumaila, 2010), are compiled in Figure 3. The brief dip in participation and expenditures was likely due to the effects of the financial recession of the early 2000s (also evident in Figure 2), and methodological changes in in-site expenditure estimation studies (Hoyt and Iñiguez, 2008). This highlights the fact that tourism is highly dependent on global economic conditions and perceptions of potential sites, so proper environmental and marketing management is of the upmost importance.

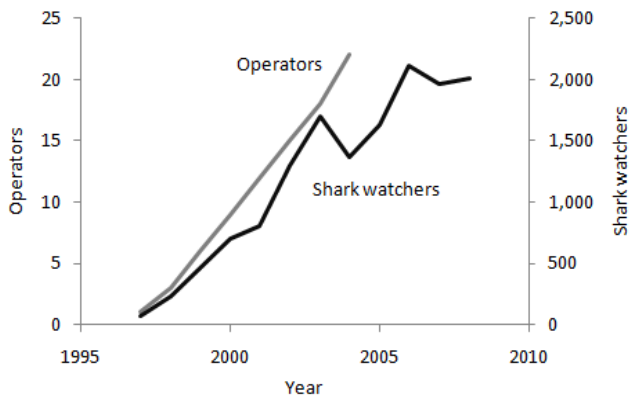

Figure 2. Shark watching growth and numbers from Gladden Spit (Source: Carne, 2008).

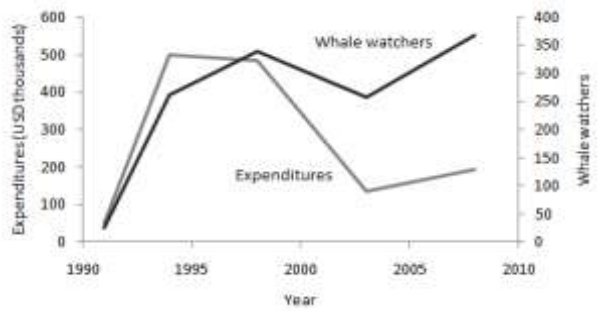

Figure 3. Whale watching participation and expenditures in Belize (Source: IFAW, 2001, 2009; Cisneros-Montemayor and Sumaila, 2010).

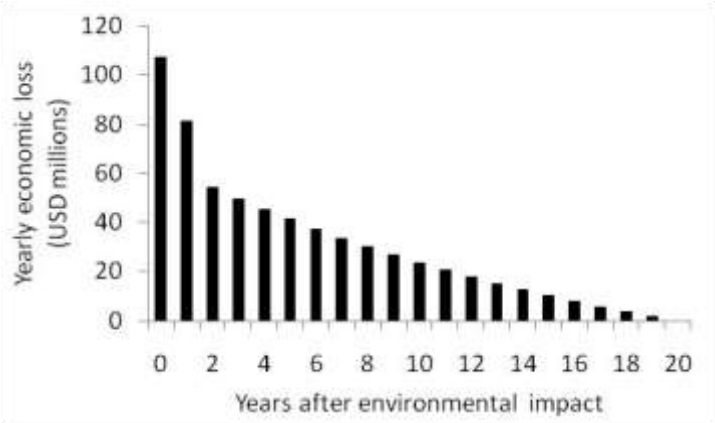

Figure 4. Yearly discounted losses in the marine ecotourism following a large-scale environmental disaster.

Marine ecotourism is a vital component of the Belizean economy, and it must be managed as such. In addition to the traditional challenges of tourism management, the two central components for marine ecotourism are the real and the perceived 'health' of the marine environment. With the improvement in information and travel options available to tourists around the world, degradation of the marine environment has an incredibly rapid impact on regional tourism. For example, hotel and charter boat cancellations following the Deepwater Horizon blow-out in 2010 were almost immediate, occurring well before the first ecological effects were seen. This is a natural and expected effect given that a significant portion of coastal tourism consists of beach-goers and recreational fishers, who realize they will not be able to enjoy their expected activities. However, the *perception* of environmental degradation or potential health concerns, even after visible oil has dissipated or recovered continues to impact tourism to the region, possibly for some years to come (Sumaila *et al.*, *in review*). These types of effects must be weighed against the possible temporary benefits of activities such as coastal development,

pollution, overfishing or oil extraction, which can compete with or harm sustainable activities such as marine ecotourism.

Oil exploration is a particularly dangerous potential threat due to its propensity for impacting large areas that are difficult to protect or clean once they have been damaged. Even with our very conservative estimates of initial tourism reduction and recovery times, both from tourist perceptions (70% and 3 years) and ecosystem status (50% and 20 years), our results suggest that, over a ten year period following an oil spill or other environmental disaster of large proportions, total losses in the marine ecotourism sector alone might reach 625 M USD in present value (Figure 4). This does not include clean-up costs or adverse health effects that may be incurred by adjacent communities, but is only a conservative estimate of lost revenue as a result of such an event. If no oil spill had occurred and assuming no further growth in the marine ecotourism, discounted benefits from this industry total to over 2 Billion USD during a 20 year period.

Our analyses and estimates are an attempt to do the most with little available data. However, it is clear that marine ecotourism is an important industry in Belize, both in economic and social terms. As such, it must be managed in an adaptive manner that ensures that the dynamic tourism market is captured, but always seeking to minimize potential ecological risks that may have direct and negative impacts on socioeconomic benefits. Here, we have chosen a hypothetical oil spill to illustrate the potential impacts following large-scale degradation of the marine environment, but there are a myriad of other potential risks, including large coastal development projects or unchecked dive tourism growth that must also be carefully considered. In addition, great care must be taken to ensure that coastal communities are the ones that benefit the most from marine ecotourism, fostering successful co-management (Finch, 2002). Perhaps the most important facet of marine ecotourism is that it directly profits from conserving the environment, creating a win-win situation (Topelko and Dearden, 2005). However, this is not always an easy balance to maintain, and it is up to the various Belizean stakeholders to foster dialogue and create adequate management plans that will ensure that these benefits are sustained.

ACKNOWLEDGEMENTS

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APPENDICES

CONFERENCE AGENDA

Too Precious to Drill: The Marine Biodiversity of Belize **Conference Agenda** **29-30 June 2011, Biltmore Best Western, Belize City**			
Date/Time	**Event/Presentation**	**Presenter/Chair**	**Affiliation/Venue**
JUNE 28	ARRIVAL OF PARTICIPANTS		
14:00 – 17:00	Registration		
JUNE 29	INTRODUCTION		
8:00 – 9:00	Late registration		
9:00 – 9:05	Welcome remarks	Tanya Williams, Coalition Coordinator	Belize Coalition to Save Our Natural Heritage
9:05 – 9:15	Welcome remarks	Senator Gordon	
9:00 – 9:15	Welcome remarks	Audrey Matura-Shepherd	Oceana Belize
9:15 – 9:30	Introduction to the Conference	Daniel Pauly	University of British Columbia
9:30 – 10:00	Offshore oil *vs* 3E's (Environment, Economy & Employment)	Frank Gordon Kirkwood and Audrey Matura-Shepherd	Retired Engineer/Independent Oil Advisor & Oceana respectively
10:00 – 10:30	The Belize Barrier Reef: a World Heritage Site	Janet Gibson	Wildlife Conservation Society Belize
10:30 – 10:45	COFFEE BREAK		
JUNE 29	THREATENED BELIZEAN MARINE BIODIVERSITY	Chairs: Melanie McField and Mike Hirschfield	Healthy Reef & Oceana respectively

Too Precious to Drill: The Marine Biodiversity of Belize **Conference Agenda** **29-30 June 2011, Biltmore Best Western, Belize City**			
Date/Time	**Event/Presentation**	**Presenter/Chair**	**Affiliation/Venue**
10:45 – 11:15	Threats to coastal dolphins from oil exploration, drilling and spills off the coast of Belize	Ellen Hines	San Francisco State University
11:15 – 11:45	The fate of manatees in Belize	Nicole Auil Gomez	Sea to Shore Alliance
11:45 – 12:15	The elasmobranchs of Glover's Reef Marine Reserve and other sites in northern and central Belize	Demian Chapman, Elizabeth Babcock, Mark Bond and Ellen Pikitch	Stony Brook University
12:15 – 14:15	LUNCH		
14:15 – 14:45	Grouper and snapper assemblages in Belize: possible impacts from oil exploration	William Heyman	Texas A&M University
14:45 – 15:15	Endemic marine fishes of Belize: evidence of isolation in a unique ecological region	Phillip Lobel	Boston University
15:15 – 15:30	COFFEE BREAK		
15:30 – 16:00	Functional importance of biodiversity for coral reefs of Belize	Janie Wulff	Florida State University
16:00 – 16:30	Biodiversity of sponges: beyond Belize and to the greater Caribbean	Maria Cristina Diaz and Klaus Ruetzler	Museo Marino de Margarita National Museum of Natural History
16:30	DINNER COCKTAILS		Sponsored by Oceana Belize and partners

Too Precious to Drill: The Marine Biodiversity of Belize **Conference Agenda** **29-30 June 2011, Biltmore Best Western, Belize City**			
Date/Time	**Event/Presentation**	**Presenter/Chair**	**Affiliation/Venue**
JUNE 30	THREATENED BELIZEAN MARINE BIODIVERSITY, CONTINUED	Chairs: Melanie McField and Mike Hirschfield	Healthy Reefs and Oceana respectively
8:30 – 9:00	Status and distribution of seabirds in Belize: threats and conservation opportunities	Lee Jones and Philip Balderamos	UNDP
9:00 – 9:30	Biodiversity, ecology and biogeography of hydroids (Cnidaria: Hydrozoa) from Belize	Lea-Anne Henry	Heriot-Watt University
9:30 – 10:00	Documenting the marine biodiversity of Belize through FishBase and SeaLifeBase	Maria L.D. Palomares and Daniel Pauly	University of British Columbia
10:00 – 10:30	Summary of marine biodiversity sessions	Mike Hirschfield	Oceana
10:30 – 10:45	COFFEE BREAK		
JUNE 30	THREATENED BELIZEAN MARINE HABITATS AND LIVELIHOODS	Chairs: Lisa Carne and Margot Stiles	Consultant and Oceana, respectively
10:45 – 11:15	Evaluating potential impacts of offshore oil drilling on the ecosystem services of mangroves in Belize	Timothy B. Smith	Brooksmith Consulting
11:15 – 11:45	A deep-sea coral 'gateway' in the northwestern Caribbean	Lea-Anne Henry	Heriot-Watt University
11:45 – 12:15	Natural and anthropogenic catastrophe on the Belizean Barrier Reef	Richard Aronson and Ian G. Macintyre	Florida Institute of Technology
12:15 – 14:15	LUNCH		
14:15 – 14:45	Evaluating coral reef health on a large scale	Melanie McField	Healthy Reefs for Healthy People
14:45 – 15:15	Reconstruction of total marine fisheries catches for Belize, 1950-2008	Dirk Zeller	University of British Columbia

Too Precious to Drill: The Marine Biodiversity of Belize **Conference Agenda** **29-30 June 2011, Biltmore Best Western, Belize City**			
Date/Time	**Event/Presentation**	**Presenter/Chair**	**Affiliation/Venue**
15:15 – 15:45	Under the threat of oil: assessing the value and contribution of Belizean fisheries	Sarah Harper and U. Rashid Sumaila	University of British Columbia
15:45 – 16:00	COFFEE BREAK		
16:00 – 16:30	The economic value and future of marine ecotourism in Belize	Andres Cisneros and U. Rashid Sumaila	University of British Columbia
16:30 – 17:00	Letter of scientists to Belizeans	Daniel Pauly	University of British Columbia
17:00 – 17:30	Conclusions and closing remarks	Audrey Matura-Shepherd & Daniel Pauly	Oceana & Sea Around Us Project respectively
18:00	DINNER		Sponsored by the *Sea Around Us* Project
JULY 1	FIELD TRIP FOR PARTICIPANTS		Turneffe Atoll
JULY 2	DEPARTURE OF PARTICIPANTS		

LETTER OF SCIENTISTS TO BELIZEANS

We, the undersigned scientists, representing 10 nationalities, have studied the diversity of marine life in Belizean waters over the last three decades.

We gathered in Belize City on June 29-30 2011 to compile and review the knowledge of this biodiversity: the living marine organisms; the plants, animals, fungi, and other species associated with the coral reefs, mangrove forests, seagrass beds, and sand and mud areas that together comprise the Belizean Barrier Reef and Atoll complex. We have also considered the vulnerability of this biodiversity to threats such as destructive fishing practices, uncontrolled effluent from land, poorly planned development on land, and both chronic and acute oil spills.

Given the enormous importance of the diversity of marine life to the Belizean economy, way of life and national pride, notably through its contributions to fisheries, tourism, and coastal protection, we urge Belizeans to fully acquaint themselves with this wealth of marine life along their coastline, and to protect it when developments- such as oil drilling- are proposed that endanger this foundation of Belize's natural wealth.

(Scientists signed here on 30 June 2011)

Conference Participants

The Organizers

Audrey Matura-Shepherd

Oceana Belize; Email: amatura-shepherd@oceana.org

Audrey is the VP of Oceana's Belize office and is a well-known public figure in Belize. She is an attorney-at-law by profession but now an environmental advocate. She began her career as a journalist, working in radio, television and print and is the founding editor of various established media outlets and has over two decades experience in this field. She remains involved in her media work as a weekly television talk show host of "Power of Attorney", which will be going into its third season and through her weekly newspaper column Right to the Point, in the most read Belizean newspaper, Amandala.

Maria Lourdes D. Palomares

The Sea Around Us Project and the SeaLifeBase Project, Fisheries Centre, University of British Columbia, 2202 Main Mall, Vancouver BC V6T1Z4 Canada ; Phone: +1 604 822 0218; Email: m.palomares@fisheries.ubc.ca

Deng is a Senior Research Associate with the Sea Around Us Project at the Fisheries Centre and the Coordinator of the SeaLifeBase Project (www.sealifebase.org). She has a PhD from the Ecole National Supérieure Agronomique de Toulouse (France) and worked with FishBase (www.fishbase.org) since its inception in 1989. Deng, with Daniel Pauly, represents the Fisheries Centre to the FishBase Consortium and continues to work closely with FishBase.

Deng will discuss on: *Documenting the marine biodiversity of Belize through FishBase and SeaLifeBase*

Daniel Pauly

The Sea Around Us Project, Fisheries Centre, University of British Columbia, 2202 Main Mall, Vancouver BC V6T1Z4 Canada; Phone: +1 604 822 1201; Email: d.pauly@fisheries.ubc.ca

Daniel is the Principal Investigator of the Sea Around Us Project. He is a French citizen who completed his high school and university studies in Germany; his doctorate (1979) and habilitation (1985) are in Fisheries Biology, from the University of Kiel. After many years at the International Center for Living Aquatic Resources Management (ICLARM), in Manila, Philippines, Daniel Pauly became in 1994 Professor at the Fisheries Centre of the University of British Columbia, Vancouver, Canada, of which he was the Director from 2003 to 2008. Since 1999, he is also Principal Investigator of the Sea Around Us Project (see www.seaaroundus.org), funded by the Pew Charitable Trusts, Philadelphia, and devoted to studying, documenting and promoting policies to mitigate the impact of fisheries on the world's marine ecosystems

Daniel will introduce this conference to the invited audience.

The Presentors

Richard Aronson

Florida Institute of Technology, Biological Sciences Department, College of Science, 150 W University Blvd OLS 500, 104 Melbourne, Florida 32901 USA; Phone: +1 321 674 8034; Email: raronson@fit.edu

Rich is currently the Head of Department at the Biological Sciences Department, College of Science at the Florida Institute of Technology. He has a Ph. D. from Harvard University and is recently involved in global climate change research, i.e., the effect of climate change on coral reefs. He has worked extensively on the ecology of lagoonal reefs in Belize notably on the historical evolution (both geological and biological) of these reefs through examination of cores.

Richard will discuss the: *Natural and anthropogenic catastrophe on the Belizean Barrier Reef*

Nicole Auil Gomez

Email: nauilgomez@gmail.com

Nicole is a biologist from Belize who is an Associate Scientist for the Florida-based Sea to Shore Alliance. Ms Gomez will talk about the fate of manatees of Belize.

She has worked in coastal conservation for 14 years and has engaged in various roles regionally and locally. She has worked with international alliances between Belize and neighboring countries on research and management initiatives, as well as teamed with local grassroots organizations serving to build their capacity to manage specific protected areas in Belize.

Nicole will discuss: *The fate of manatees in Belize*

Demian Chapman

Stony Brook University, School of Marine and Atmospheric Science, Stony Brook, NY 11794 USA; Phone: +1 631 632 8731; E-mail: demian.chapman@stonybrook.edu

Demian is an Assistant Professor at the School of Marine and Atmospheric Science, Stony Brook University, New York. His primary research interests lie in elucidating dispersal and reproductive patterns in marine vertebrates (principally elasmobranch fishes) by integrating genetic and electronic tagging data, with a particular focus on how these patterns influence the spatial structure of genetic variation, population dynamics and apply to conservation. He is also interested in the development of wildlife forensic techniques and resources for law enforcement and trade monitoring purposes.

Demian will discuss: *The elasmobranchs of Glover's Reef Marine Reserve and other sites in northern and central Belize*

THE PRESENTORS (CONTINUED)

ANDRES CISNEROS-MONTEMAYOR

University of British Columbia, Fisheries Centre, 2202 Main Mall, Vancouver BC V6T1Z4 Canada ; Email: a.cisneros@fisheries.ubc.ca

Andrés has a BSc in Marine Biology from the Universidad Autónoma de Baja California Sur, La Paz, Mexico, and an MSc in Resource Management and Environmental Studies from the University of British Columbia, Vancouver, Canada. He believes that fisheries scientists have a responsibility to study the many aspects of fisheries in the context of improving the quality of life for the people and communities that depend on them; conserving (and perhaps restoring) marine ecosystems is perfectly compatible with this. His MSc. thesis focused on assessing the benefits and possible impacts of the growing marine recreation industry in order to identify potential alternatives for fishermen. His current PhD work uses ecosystem models to help explore the role of socioeconomic conditions in achieving successful marine resource management. Having grown up around fisheries, he appreciates the fact that knowing how many fish are caught and catching them is not the problem; he hopes that economics may help to understand and ultimately solve current problems in fisheries and marine ecosystem management.

Andres will discuss: *The economic value and future of marine ecotourism in Belize*

SARAH HARPER

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Sarah is a Senior Research Assistant with the Sea Around Us Project. She works with Dr Dirk Zeller on the reconstruction of fisheries catches. She has an MSc in marine resources management from the Heriott-Watt University in Edinburgh, Scotland. She worked the Smithsonian Tropical Research Institute in Panama for her dissertation on habitat mapping of a proposed marine protected area in the Las Perlas Archipelago, Panama.

Sarah will discuss: *Under the threat of oil: assessing the value and contribution of Belizean fisheries*

MARIA CRISTINA DIAZ

Museo Marino de Margarita, Boulevard El Paseo, Boca del Rio, Peninsula de Macanao, Nueva Esparta, Venezuela; Email: taxochica@gmail.com

Cris is a research associate at the Museo Marino de Margarita in Venezuela, and a visiting scientist at the National Museum of Natural History, Washington DC. (PhD from the University of California, Santa Cruz). She applies traditional and molecular approaches to study sponge biodiversity and ecology, for over 20 years, focusing on sponge-microbe nitrification, sponge-cyanobacteria associations, sponge systematics and biogeography. Cris is very interested in marine sponge biodiversity, both from a present and an historical perspective. She collaborates with other taxonomists, natural product researchers, microbiologists, and ecologists to explore the Caribbean, the South Pacific, and the Indian Ocean. Cris and Bob Thacker created a course, Taxonomy and Ecology of Caribbean Sponges (www.stri.org, Diaz *et al.*, 2006), which has introduced 40 young scientists to the science of sponge taxonomy and ecology and its applications.

Cris will discuss the: *Biodiversity of sponges: beyond Belize and to the greater Caribbean*

LEA-ANNE HENRY

Scottish Association of Marine Science, Oban, Argyll, UK; Email: leaanne.roberts@gmail.com

Lea-Anne is a Research Fellow with the Centre for Marine Biodiversity and Biotechnology at Heriot-Watt University in Edinburgh, UK, a member of the Marine Alliance for Science and Technology for Scotland. Her interests include the biodiversity, biogeography and ecology of benthic marine epifauna, particularly the benthic hydrozoans (hydroids). She has worked on deep-sea 'cold-water corals' and their associated biodiversity since 2000, and is a Charter Member of the Canadian Centre for Marine Biodiversity (http://www.marinebiodiversity.ca). Her current research involves an interdisciplinary look into factors that control the biodiversity and biogeography of fauna inhabiting deep cold-water coral reefs. This work is amphi-Atlantic in scope, with the objective of linking data acquired from acoustic remote-sensing methods (sidescan, multibeam) to ground-truthed species composition data across multiple spatial scales. She has worked with colleagues to develop the Trans-Atlantic Coral Ecosystem Study since its inception in 2008 (http://www.lophelia.org/traces) and helps maintain the online resource Lophelia.org (www.lophelia.org), dedicated to advancing public knowledge about cold-water corals.

Lea-Anne has two presentations: *Biodiversity, ecology and biogeography of hydroids (Cnidaria: Hydrozoa) from Belize* and *A deep-sea coral 'gateway' in the northwestern Caribbean*

JANET GIBSON

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Janet is a biologist and is the Country Director for the Wildlife Conservation Society in Belize and is involved with the management, education and research of marine ecosystems in Belize. She was awarded the Goldman Environmental Prize in 1990 for her efforts on conservation of the marine ecosystems outside the Belizean coast, in particular the barrier reef system. The Belize Barrier Reef was granted UNESCO World Heritage status in 1996.

Janet will discuss: *The Belize Barrier Reef: a World Heritage Site*

WILLIAM D. HEYMAN

Texas A&M University, Department of Geography, Texas, Texas USA; Phone: +1 979 845 5411; Email: wheyman@tamu.edu

Will is Associate Professor at the Department of Geography at Texas A&M University. He developed a broad interest in science and sustainable management of tropical coastal and marine systems from the time he was a child. He graduated from Tufts University with a major in Marine Biology and Environmental Studies in 1983. He then spent three years working in marine aquaculture in the Bahamas, Turks and Caicos, and the Marshall Islands. He did his MSc and PhD through the University of South Carolina, conducting field research in both the Marshall Islands and Belize, finishing in 1996. In 7 years of graduate work, he spent only 5 semesters in residence, gaining the dubious honor of the student with the most degrees, and least amount of time on campus at USC. Meanwhile, he began working for the International Division of the Nature Conservancy in Belize where he lived for ten years. He is now an Associate Professor of Geography.

THE PRESENTORS (CONTINUED)

ELLEN M. HINES

San Francisco State University, Department of Geography and Human Environmental Studies, 1600 Holloway Ave., San Francisco, California 94132 USA; Email: ehines@sfsu.edu

Ellen has a Ph. D. from the University of Georgia. She is currently an Associate Professor at the San Francisco State University and Director of the Marine & Coastal Conservation and Spatial Planning Center at San Francisco State University, part of the Institute for Geographic Information Science, a research center dedicated to utilizing and developing the most relevant, powerful and practical geospatial tools to contribute to interdisciplinary marine and coastal conservation. The faculty, students and collaborators seek to describe, model and predict the effects of human use on the marine and coastal environment. This includes habitat modeling and mapping for marine endangered species and ecosystems, sea level change scenarios, documenting of human use and values. She is interested in research that explores tools to facilitate the creation, implementation, and subsequent monitoring of localized scientific and conservation oriented management.

Ellen will discuss the: *Threats to coastal dolphins from oil exploration, drilling and spills off the coast of Belize*

H. LEE JONES

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Lee has a PhD in avian biogeography from UCLA. He is internationally recognized as an authority in ornithology and is one of the leading field ornithologists in Central America. In addition to birds, his taxonomic knowledge embraces the vascular plants, the major terrestrial vertebrate groups and, among invertebrates, the Lepidoptera. By profession, he is an environmental consultant and research biologist. For the past two decades he has resided part-time in Belize where he has been conducting research on the country's birds and other wildlife. He also volunteers as a technical advisor to various conservation organizations including the Belize Audubon Society, Birds Without Borders/Aves Sin Fronteras, Programme for Belize, Toledo Institute for Development and the Environment (TIDE), and Ya'axché Conservation Trust (YCT).

Lee will discuss the: *Status and distribution of seabirds in Belize: threats and conservation opportunities*

FRANK GORDON KIRKWOOD

Independent Petroleum Engineering & Economics Consultant, Belize City; Email: kirkwoodg@ymail.com

Gordon obtained his PhD in Chemical Physics from the University of Kent at Canterbury in 1979. He worked thirty years in the oil and gas industry for BP as a Petroleum Engineer and Commercial Advisor in various locations worldwide (UK, Egypt, Venezuela and the United Arab Emirates). He is a Chartered Engineer in the UK, a European Engineer and a Fellow of the Institute of Materials, Mining and Metallurgy. During his retirement he has volunteered as an Independent Oil Advisor to Oceana Belize, consulted with Dive Centers on their Emergency Procedures and provided underwater photographs to Dive Centers. He is also a member of the Marine Mammal Stranding network and a helps to run the Belize Humane Society and Animal Center.

Gordon will discuss: *Offshore oil vs 3E's (Environment, Economy & Employment)*

MELANIE MCFIELD

Healthy Reefs for Healthy People Initiative, Smithsonian Institution, 1755 Coney Dr, Belize City, Belize; Phone: +501 223 4898; Email: mcfield@healthyreefs.org

Melanie McField is the Director of the Healthy Reefs for Healthy People Initiative (HRI) based in Belize City, Belize. She is employed by the Smithsonian Institution and serves on a number of national and international marine conservation and research committees, including the Council of the International Society of Reef Studies. Melanie has lived and worked in Belize since 1990; first as a field biologist with the Hol Chan Marine Reserve (and Peace Corps volunteer), then with and Coastal Zone Management Authority and Institute, and later with World Wildlife Fund. Melanie earned a PhD degree (2001) at the College of Marine Science, University of South Florida, after receiving the first International Society of Reef Studies Coral Reef Ecosystem Science Fellowship for her dissertation research exploring the role of disturbance events and the impact of marine protected areas on coral reef community structure in Belize. Melanie has published numerous scientific manuscripts, book chapters and technical reports on topics ranging from coral bleaching to coral reef monitoring methods, marine protected areas and coral reef management. She has also been featured on several television appearances including the TODAY show, National Geographic, Animal Planet and the BBC.

Melanie will discuss on: *Evaluating coral reef health on a large scale*

PHILLIP S. LOBEL

Boston University, Biology Department, Boston, MA 02215 USA; Phone: +1 617 358 4586; Email: plobel@bu.edu

Phil is a professor of Biology at the Boston University. His areas of interest are ichthyology; behavioral ecology and taxonomy of fishes. He is interested in fundamental concepts of fish biology and in applying this knowledge to scientific issues and to societal concerns of fisheries management and conservation. His scientific work has focused on field studies of fish behavior and ecology. He has worked in a variety of habitats worldwide where fishes are a significant component of the fauna. In recent years, he has applied his scientific expertise to contemporary problems in conservation biology and environmental protection. From 1983 to 2003, his main study site was Johnston Atoll, Central Pacific Ocean conducting research as part of the US Army marine ecological monitoring program evaluating operation of the Johnston Atoll Chemical Weapons Disposal System. Since 2003, he has been working primarily in Belize, Central America on fish ecology and discovery of new species.

Phil will discuss the: *Endemic marine fishes of Belize: evidence of isolation in a unique ecological region*

TIMOTHY SMITH

Brooksmith Consulting, Illinois, USA; E-mail:timothy@tbrooksmith.com

Tim (M.S., Biology, University of Illinois) is the founder of Brooksmith Consulting, a company dedicated to projects in aquatic ecology associated with ecosystem integrity, water quality, ecosystem management, fisheries, and education. Tim has twenty-one years of experience dealing with applied ecological issues and the detection, quantification and management of a wide variety of ecological disturbances. Tim's work has helped provide a scientific basis for Total Maximum Daily Load (TMDL) regulations in aquatic ecosystems for the Environmental Protection Agency in the US. He has also been instrumental in restoring coastal seagrass and mangrove ecosystems in Belize.

Tim will discuss: *Evaluating potential impacts of offshore oil drilling on the ecosystem services of mangroves in Belize*

THE PRESENTORS (CONTINUED)

JANIE WULFF

Department of Biological Science, Florida State University, Tallahassee, FL, USA; wulff@bio.fsu.edu

Janie is the Associate Professor of Biology at Florida State University. She does underwater research on sponges, corals, and other sessile clonal animals, that inhabit coral reefs, seagrass eadows, and mangrove prop roots. Her focus is on ecological interactions, especially mutually beneficial associations that ameliorate the influence of predators, competitors, and abiotic environmental challenges for all participating species. Her first underwater experiments, in Belize (Lighthouse Atoll) in 1977, demonstrated that sponges can improve the survival of corals by an order of magnitude, even though they may appear to be competing with THEM. Some of her publications ARE LISTED at: http://www.bio.fsu.edu/faculty-wulff.php.

Janie will discuss the: *Functional importance of biodiversity for coral reefs of Belize*

DIRK ZELLER

The Sea Around Us Project, Fisheries Centre, University of British Columbia, 2202 Main Mall, Vancouver BC V6T1Z4 Canada; Phone: +1 604 822 1950; Email: d.zeller@fisheries.ubc.ca

Dr Dirk Zeller is Sea Around Us Project's Senior Research Fellow and Project Manager. Dirk leads a catch data reconstruction team and associated projects that deal with Illegal, Unreported and Unregulated fishing by deriving more accurate estimates of total catches by countries. He contributed such data to stock assessment collaborations with the Fisheries Centre Quantitative Modeling Group for Hawaiian bottom fish assessments, and illustrated that ICES (EU) catch data for the Baltic Sea substantially underreport total catches. Dirk also investigates coral reef fisheries (e.g., Coral Triangle Initiative) and global marine pollution modelling, engages in ocean governance and fisheries policy research (e.g., FishEU international policy working group), and collaborates with the Fisheries Economics Research Unit on issues in resource economics, and with the UBC Faculty of Law on issues related to international maritime boundary law and the UN Law of the Sea Convention. He also directs day-to-day research activities and management issues of the Project, and actively engages in and directs strategic research and funding decisions in close coordination with Daniel Pauly.

Dirk will discuss the: *Reconstruction of total marine fisheries catches for Belize, 1950-2008*