Growth modelling indicates hurricanes and severe storms are linked to low coral recruitment in the caribbean

M. James C. Crabbe, Edwin Martinez, Christina Garcia, Juan Chub, Leonardo Castro, Jason Guy

► To cite this version:

M. James C. Crabbe, Edwin Martinez, Christina Garcia, Juan Chub, Leonardo Castro, et al.. Growth modelling indicates hurricanes and severe storms are linked to low coral recruitment in the caribbean. Marine Environmental Research, 2008, 65 (4), pp.364. 10.1016/j.marenvres.2007.11.006 . hal-00501930

HAL Id: hal-00501930

<https://hal.science/hal-00501930>

Submitted on 13 Jul 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Accepted Manuscript

Growth modelling indicates hurricanes and severe storms are linked to low coral recruitment in the caribbean

M. James C. Crabbe, Edwin Martinez, Christina Garcia, Juan Chub, Leonardo Castro, Jason Guy

PII: S0141-1136(07)00148-1
DOI: [10.1016/j.marenvres.2007.11.006](https://doi.org/10.1016/j.marenvres.2007.11.006)
Reference: MERE 3158

To appear in: *Marine Environmental Research*

Received Date: 30 August 2007
Revised Date: 21 November 2007
Accepted Date: 22 November 2007

Please cite this article as: Crabbe, M.J.C., Martinez, E., Garcia, C., Chub, J., Castro, L., Guy, J., Growth modelling indicates hurricanes and severe storms are linked to low coral recruitment in the caribbean, *Marine Environmental Research* (2007), doi: [10.1016/j.marenvres.2007.11.006](https://doi.org/10.1016/j.marenvres.2007.11.006)

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

SHORT COMMUNICATION

GROWTH MODELLING INDICATES HURRICANES AND SEVERE STORMS
ARE LINKED TO LOW CORAL RECRUITMENT IN THE CARIBBEAN

M. James C. Crabbe ¹, Edwin Martinez ², Christina Garcia ³, Juan Chub ⁴, Leonardo
Castro ⁵ and Jason Guy ⁶

¹,Luton Institute for Research in the Applied Natural Sciences,
Faculty of Creative Arts, Technologies and Science, University of Bedfordshire, Park
Square, Luton, LU1 3JU, U.K.; ², Belize Regional Initiative, Earthwatch Institute, Joe
Taylor Creek Bridge, Punta Gorda Town, Belize, Central America; ³, Toledo
Association for Sustainable Tourism and Empowerment (TASTE), 53 Main Middle
Street, P.O.Box 18. Punta Gorda Town, Toledo, Belize Central America; ⁴, Toledo
Institute for Development and Environment (TIDE), P.O. Box 150, 1 Mile San
Antonio Road, Punta Gorda Town, Toledo, Belize Central America; ⁵, Friends of
Nature, Belize, Village of Placencia, Stann Creek District, Belize, Central America; ⁶,
Belize Department of Fisheries, Coastal Zone Multi-Complex Building, Princess
Margaret Drive, P.O. Box 148, Belize City, Belize Central America.

Corresponding author: MJC Crabbe: email: james.crabbe@beds.ac.uk; Tel: +44 (0)
1582489265; Fax: +44 (0) 1582489212

Keywords: tropical storms, cyclones, climate change, global warming, coral growth

1 ABSTRACT

2 This study set out to test the hypothesis that hurricanes and tropical storms limit the
3 recruitment and subsequent survival of massive non-branching corals on the barrier
4 reef off the coast of Belize in the Gulf of Honduras. Overall, the surface areas of 523
5 individual coral specimens were measured, and recruitment dates were then modelled.
6 There was no significant difference in coral cover or coral biodiversity between any of
7 the sites studied ($p>0.1$). There were significant differences in non-branching coral
8 recruitment in years when hurricanes impacted the area ($p<0.05$) compared with years
9 when no hurricanes impacted the area. There were significantly more non-branching
10 massive corals recruited in non-hurricane years (mean 7.7) than in hurricane years
11 (mean 3.8; $p=0.011$). When years with tropical storms are added to the years with
12 hurricanes, there was significantly lower coral recruitment (mean 4.7) relative to non-
13 storm or hurricane years (mean 7.4; $p=0.019$). These results show that hurricanes and
14 severe storms limited the recruitment and survival of massive non-branching corals of
15 the Mesoamerican barrier reef and on patch reefs near the Belize coast in the
16 Caribbean, and suggests that marine park managers may need to assist coral
17 recruitment in years where there are hurricanes or severe storms.

18

19

20

21

22

23

1

2 1. INTRODUCTION

3 There is observational evidence for an increase of intense tropical cyclone
4 activity in the North Atlantic since about 1970, correlated with increases of tropical
5 sea surface temperatures (IPCC, 2007). Based on a range of models, it is likely that
6 future tropical cyclones (typhoons and hurricanes) will become more intense, with
7 larger peak wind speeds and more heavy precipitation associated with ongoing
8 increases of tropical SSTs (IPCC, 2007). An increasing amount of evidence is now
9 accumulating for a direct relationship between global warming and increasing
10 hurricane intensity as well as increasing hurricane frequency (Elsner et al., 2006a, b).
11 Global warming produces significant increases in the frequency of high sea surface
12 temperatures (SSTs) (Hoegh-Guldberg, 1999), and hurricane winds are strengthened
13 by warm surface waters. Our recent work on the effects of temperature on coral
14 growth on fringing reefs off the coast of Curaçao suggest that a 30-day averaged
15 maximum daily temperature can explain about 3% of the variability in the time-
16 dependent growth rate (Crabbe et al., 2008), suggesting that during the measurement
17 period, temperatures rose to higher than optimum temperatures for growth, thus
18 inhibiting coral growth, but were not sufficiently high to cause bleaching of this
19 species. This result points to the very narrow temperature range for coral growth, and
20 to how sensitive corals are to fluctuations in temperature, particularly to rates of
21 temperature change (Dodge and Lang, 1983; Dodge and Brass, 1984; Dunbar et al.,
22 1994; Crabbe, 2007).

23 Maintaining coral reef populations in the face of large scale degradation and
24 phase-shifts on reefs depends critically on recruitment (Hughes, 1994; Hughes and
25 Tanner, 2000; Coles and Brown, 2007), and the present study set out to test the
26 hypothesis that hurricanes and tropical storms limit the recruitment and subsequent
27 survival of massive non-branching corals. We have shown previously, using

modeling based on growth rate data, that this was the case on the fringing reefs of the north coast of Jamaica near Discovery Bay (Crabbe et al., 2002; 2004), and now wished to test that hypothesis on the barrier reef off the coast of Belize, in the Sapodilla Cayes Marine Reserve, and in the patch reefs in the Port Honduras Marine Reserve, near to Punta Gorda Town in Belize, in the Gulf of Honduras.

METHODS

SITES

There are two major coral reef areas in Southern Belize, the Sapodilla Cayes Marine Reserve (SCMR, a World Heritage Site), and the Port Honduras Marine Reserve (PHMR). The SCMR is a 125 km² reserve and has had a collaborative agreement with the Belize Fisheries Department and the Toledo Association for sustainable Tourism (TASTE) to manage the area since its declaration in 1996. The PHMR is a 414 km² reserve, and has been managed by the Toledo Institute for Development and Environment (TIDE) since its declaration in January 2000. Sample sites were selected from both reserves (Fig. 1), and GPS coordinates (given in the legend to Fig. 1) were determined using a hand-held GPS receiver. Basic water quality measurements were made at one PHMR site (South Snake Caye) in August 2006, with results as follows: salinity – 34.14.ppt; temperature – 30.1 °C; dissolved oxygen- 81.1% saturation; pH – 8.48; Turbidity- 0.1 Nephelometric Turbidity Units (NTU); phosphates – 0.22 mg/l; nitrates- 0.4 mg/l; chlorophyll – 0.1 mg.l. This work was conducted in July and August 2006, and in August 2007.

SAMPLING

Coral cover was determined at each site using the line intercept transect method, over haphazardly allocated 10m transects at each site above (Osborne and Oxley, 1977). Surface areas of live non-branching corals were determined at the sites as described

previously using SCUBA (Crabbe et al., 2002; 2004; Crabbe and Smith, 2003; 2005). 74% of the samples came from SCMR sites, 26% from PHMR sites. Calculations on the samples showed no significant differences in recruitment between the sites in the SCMR, and likewise for sites in the PHMR. Depth of samples was between 8-12 m, to minimise variation in growth rates due to depth (Huston, 1985). To increase accuracy, surface areas rather than diameters of live non-branching corals were measured. Sampling was over as wide a range of sizes as possible, but no corals ≤ 5 mm in diameter were measured. Colonies that were close together (<5 cm) or touching were avoided to minimise age discontinuities through fission and altered growth rates (Hughes and Jackson, 1980; Elahi and Edmunds, 2007), and we took pains to measure corals that were widely spaced apart. Overall, 523 individual coral specimens were measured. These included the major species measured (numbers of individuals in brackets): *Agaricia agaricites* (23), *Agaricia tenuifolia* (39), *Colpophyllia natans* (49), *Dichocoenia stokesii* (17), *Diploria labyrinthiformis* (24), *Diploria strigosa* (48), *Montastrea annularis* (10), *Montastrea cavernosa* (61), *Montastrea faveolata* (26), *Montastrea franksei* (32), *Meandrina meandrites* (10), *Mycetophyllia* spp. (23), *Porites astreoides* (58), *Porites porites* (21), *Siderastrea siderea* (37), *Stephanocoenia intersepta* (13).

The year of an individual's recruitment was calculated from a knowledge of the growth rate (e.g. 3.25 mm/yr for *Porites astreoides*, 3 mm/yr for *Siderastrea siderea*) (Dodge and Vaisnys, 1975; Hubbard and Scaturo, 1985; Huston, 1985; Carricart-Ganivet et al., 2000), taken from sites in the Caribbean at similar depths and visibility to those encountered here, the majority from Huston (1985). For example, a *Porites astreoides* colony of measured elliptical surface area 51.8 cm² was estimated to have recruited (and survived) 23 years ago. We modelled changes to the growth rates similar to those encountered at different sites and similar depths from the references above, and in none of the colonies studied did this amount to a change in estimated

1 recruitment date of < 2 years over 50 years. One or two-factor ANOVA was used to
 2 compare coral data among sites; $\pm$ error values represent standard deviations of the
 3 data.

4

5 DATA ON STORMS AND HURRICANES IMPACTING BELIZE

6 Data on storm severity as it impacted the SCMR AND PHMR areas was
 7 obtained from UNISYS (<http://weather.unisys.com/hurricane/atlantic/>) the NOAA
 8 hurricane site (<http://www.nhc.noaa.gov/pastall.shtml>) and the Belize tropical storm
 9 site: <http://www.hurricanecity.com/city/belize.htm>.

10

11 3. RESULTS

12 There was no significant difference in coral cover or coral biodiversity between
 13 the sites in the SCMR (24% $\pm$ 10% coral cover overall), or in the PHMR (17% $\pm$
 14 7% coral cover overall), or between the PHMR and SCMR ($p>0.1$), although there
 15 were no *Acropora palmata* branching colonies in the PHMR sites.

16 Fig. 2a shows the estimated recruitment dates for all 523 non-branching corals at
 17 the SCMR and PHMR sites. Solid arrows show the years of hurricanes which
 18 impacted the area, with their names (the hurricane in 1931 had no name); dotted
 19 line arrows show the years where tropical storms impacted the area. Fig 2b shows
 20 that there are significant differences in non-branching coral recruitment in years
 21 when hurricanes impacted the area ($p<0.005$ for PHMR, $p<0.05$ for SCMR)
 22 compared with years when no hurricanes impacted the area. Overall, for both the
 23 PHMR and the SCMR, there were significantly more non-branching massive
 24 corals recruited in non-hurricane years (mean 7.7 $\pm$ 5.6) than in hurricane years
 25 (mean 3.8 $\pm$ 2.9; $p=0.011$). When years with tropical storms are added to the
 26 years with hurricanes, there was significantly lowered coral recruitment (mean 4.7
 27 $\pm$ 4.3) relative to non-storm or hurricane years (mean 7.4 $\pm$ 5.7; $p=0.019$).

4. DISCUSSION

Multiple stressors, hurricanes and bleaching, have caused significant disturbances to populations of coral recruits in Belize (Mumby, 1999). Hurricanes and tropical storms cause major damage and delayed mortality to corals (Knowlton et al., 1981; Done, 1999), as happened with hurricane Allen in 1980 to the fringing reefs off Discovery Bay in Jamaica (Woodley et al., 1981). Alteration of substratum by storms reduces recruitment rates, as does the pre-emption of space by other corals or macroalgae (Connell, 1997; Connell et al., 1997). Ecosystem thresholds have been modelled to identify targets for reef restoration (Mumby et al., 2007), and it appears that grazing, for example by parrotfish, is critical to reef resilience and restoration in the face of continuing hurricane intensity (Bythell et al., 2000; Mumby et al., 2007). While we have not measured coral recruitment directly in this study, our modelling work has shown that hurricanes and severe storms have limited the recruitment and survival of massive non-branching corals on the fringing reefs near Discovery Bay (Crabbe et al., 2002; 2004), and here we show that the same is true for non-branching corals of the Mesoamerican barrier reef in the Sapodilla Cayes, and for corals on patch reefs in the Port Honduras Marine Reserve near the Belize coast in the Gulf of Honduras. While occasional storms can increase the survivorship of branching *Acropora palmata* colonies (Lirman, 2003), storm-induced decrease in reef rugosity can limit the settlement of coral planulae, as survival is greater in the shade or under surfaces (Birkland, 1977). While some coral communities may adapt to chronic stressors, for example sedimentation, over long periods of time (Flood et al., 2005), acute stresses such as those induced by high wave energy during storms could reduce the reproductive output of corals (Ward, 1995; Baird and Marshall, 2002), and thus lower coral recruitment. Storms and hurricanes can influence sedimentation and

turbidity, which themselves have significant effects on coral growth (Gilmour, 1999; Crabbe and Carlin, 2007). Increased freshwater inputs from storms reduces salinity, which in turn increases pre-and post-settlement mortality, changed larval behaviour and substrate choice upon settlement (Vermeij et al., 2006). What our work suggests is that marine park managers may need to assist coral recruitment and settlement in years where there are hurricanes or severe storms, by setting up coral nurseries (Forsman et al., 2006) and / or natural or artificial high rugosity substrate on the reef.

Acknowledgements

We thank the Earthwatch Institute and the Oak Foundation (USA) for funding, and Burton Shank (Conservation International) for essential help with the GPS coordinates. We also thank Dennis and Sandra Garbutt for their vital organisational support during the project, and the anonymous referees for suggesting improvements to the manuscript.

References

- Baird, A.H., Marshall, P.A., 2002. Mortality, growth and reproduction in scleractinian corals following bleaching on the Great Barrier Reef. *Marine Ecology Progress Series* 237, 133-141.
- Bythell, J.C., Hillis-Star, Z.M., Rogers, C.S., 2000. Local variability but landscape stability in coral reef communities following repeated hurricane impacts. *Marine Ecology Progress Series* 204, 93-100.
- Birkeland, C., 1977. The importance of rate of biomass accumulation in early successional stages of benthic communities to the survival of coral recruits. *Proceedings of the 3rd. International Coral reef Symposium* 15-21.

1

2 Carricart-Ganivet, J.P., Beltrán-Torres, A.U., Merino, M., Ruiz-Zárate, M.A., 2000.

3 Skeletal extension, density and calcification rate of the reef building coral *Montastrea*

4 *annularis* (Ellis and Solander) in the Mexican Caribbean. Bulletin of Marine Science

5 66, 215-224.

6

7 Coles, S.L., Brown, E.K., 2007. Twenty-five years of change in coral coverage on a

8 hurricane impacted reef in Hawai'i: the importance of recruitment. Coral Reefs 26,

9 705-717.

10

11 Connell, J. H., 1997. Disturbance and recovery of coral assemblages. Coral Reefs 16,

12 S101-S113.

13

14 Connell, J.H., Hughes, T.P., Wallace, C.C., 1997. A 30-year study of coral abundance,

15 recruitment, and disturbance at several scales in space and time. Ecological

16 Monographs 67, 461-488

17

18 Crabbe, M.J.C., 2007. Global warming and coral reefs: modelling the effect of

19 temperature on *Acropora palmata* colony growth. Computational Biology and

20 Chemistry 31, 294-297.

21

22 Crabbe, M.J.C., Smith, D.J., 2003. Computer modelling and estimation of

23 recruitment patterns of non-branching coral colonies at three sites in the Wakatobi

24 Marine Park, SE Sulawesi, Indonesia; Implications for coral reef conservation.

25 Computational Biology and Chemistry 27, 17-27.

26

- 1 Crabbe, M.J.C., Smith, D.J., 2005. Sediment impacts on growth rates of *Acropora* and
2 *Porites* corals from fringing reefs of Sulawesi, Indonesia. *Coral Reefs* 24, 437-441.
3
- 4 Crabbe, M.J.C., Carlin, J.P., 2007. Industrial sedimentation lowers coral growth rates
5 in a turbid lagoon environment, Discovery Bay, Jamaica. *International Journal of*
6 *Integrative Biology* 1, 37-40.
7
- 8 Crabbe, M.J.C., Mendes, J.M., Warner, G.F., 2002. Lack of recruitment of non-
9 branching corals in Discovery Bay is linked to severe storms. *Bulletin of Marine*
10 *Science* 70, 939-945.
11
- 12 Crabbe, M.J.C., Karaviotis, S., Smith, D.J., 2004. Preliminary comparison of three
13 coral reef sites in the Wakatobi Marine National Park (S.E. Sulawesi, Indonesia):
14 Estimated recruitment dates compared with Discovery Bay, Jamaica. *Bulletin of*
15 *Marine Science* 74, 469-476.
16
- 17 Crabbe, M.J.C., Walker, E.L.L., Stephenson, D.B., 2008. The impact of weather and
18 climate extremes on coral growth. In : H. Diaz & R. Murnane (Eds.) *Climate*
19 *Extremes and Society*. Cambridge University Press. In the press.
20
- 21 Dodge, R.E., Vaisnys, J.R., 1975. Hermatypic coral growth banding as an
22 environmental recorder. *Nature* 258, 706-708.
23
- 24 Dodge, R.E., Lang, J.C., 1983. Environmental correlates of hermatypic coral
25 (*Montastrea annularis*) growth on the East Flower Gardens Bank, northwest Gulf of
26 Mexico. *Limnology and Oceanography* 28, 228-240.
27

- 1 Dodge, R.E., Brass, G.W., 1984. Skeletal extension, density and calcification of the
2 reef coral *Montasrea annularis*: St. Croix U.S.Virgin Islands. Bulletin of Marine
3 Science 34, 288-307.
- 4
- 5 Done, T. J., 1999. Coral community adaptability to environmental change at the scales
6 of regions, reefs and reef zones. American Zoologist 39, 66-79.
- 7
- 8 Dunbar, R. B., Wellington, G.M., Colgan, M.W., Glynn, P.W.,1994. Eastern Pacific
9 sea surface temperature since 1600 A.D.: The $\delta^{18}\text{O}$ record or climate variability in
10 Galápagos corals. Paleoceanography, 9, 291–316.
- 11
- 12 Elahi, R., Edmunds, P.J., 2007. Consequences of fission in the coral *Sidastrea*
13 *siderea*: growth rates of small colonies and clonal input to population structure. Coral
14 Reefs 26, 271-276.
- 15
- 16 Elsner, J.B., Jagger, T.H., Tsonis, A.A., 2006a. Estimated return periods for Hurricane
17 Katrina. Geophysical Research Letters 33, doi:10.1029/2006GL025452.
- 18
- 19 Elsner, J.B., Murnane, R.J., Jagger, T.H., 2006b. Forecasting U.S. hurricanes 6
20 months in advance. Geophysical Research Letters 33, doi:10.1029/2006GL025693.
- 21
- 22 Flood, V.S., Pitt, J.M., Smith, S.R., 2005. Historical and ecological analysis of coral
23 communities in Castle Harbour (Bermuda) after more than a century of environmental
24 perturbation. Marine Pollution Bulletin 51, 545-557.
- 25

- 1 Forsman, Z.H., Rinkevich, B., Hunter, C.L., 2006. Investigating fragment size for
2 culturing reef-building corals (*Porites lobata* and *P-compressa*) in ex situ nurseries.
3 *Aquaculture* 261, 89-97.
4
- 5 Gimour, J.P. 1999. Experimental investigation into the effects of suspended sediment
6 on fertilisation, larval survival and settlement in scleractinian coral. *Marine Biology*
7 135, 451-462.
8
- 9 Hoegh-Guldberg, O., 1999. Climate change, coral bleaching and the future of the
10 world's coral reefs. *Marine and Freshwater Research* 50, 839-866.
11
- 12 Hubbard, D.K., Scaturo, D., 1985. Growth rates of 7 species of scleractinian corals.
13 *Bulletin of Marine Science* 36, 325-338.
14
- 15 Hughes, T.P., 1994. Catastrophes, phase shifts and large scale degradation of a
16 Caribbean coral reef. *Science* 265, 1547-1551.
17
- 18 Hughes, T.P., Jackson, J.B.C., 1980. Do corals lie about their age? Some demographic
19 consequences of partial mortality, fission, and fusion. *Science* 209, 713-715.
20
- 21 Hughes, T.P., Tanner, J.E., 2000. Recruitment failure, life histories and long-term
22 decline of Caribbean corals. *Ecology* 81, 2250-2263.
23
- 24 Huston, M., 1985. Variation of coral growth rates with depth at Discovery Bay,
25 Jamaica. *Coral Reefs* 4, 19-25.
26

- 1 IPCC, 2007. Intergovernmental Panel on Climate Change (IPCC), Summary for
2 Policymakers from Working Group I. <http://www.ipcc.ch/SPM2feb07.pdf>
3
- 4 Knowlton, N., Lang, J.C., Rooney, M.C., Clifford, P., 1981. Evidence for delayed
5 mortality in hurricane-damaged Jamaican staghorn corals. *Nature* 294, 251-252.
6
- 7 Lirman, D., 2003. A simulation model of the population dynamics of the branching
8 coral *Acropora palmata* - effects of storm intensity and frequency. *Ecological*
9 *Modelling* 161, 169-182.
10
- 11 Mumby, P.J., 1999. Bleaching and hurricane disturbances to populations of coral
12 recruits in Belize. *Marine Ecology Progress Series* 190, 27-35.
13
- 14 Mumby, P.J., Hastings, A., Edwards, H.J., 2007. Thresholds and the resilience of
15 Caribbean coral reefs. *Nature* 450, 98-101.
16
- 17 Osborne, K., Oxley, W.G., 1977. Sampling benthic communities using video transects.
18 In : English, S., Wilkinson, C. and Baker, V. (Eds.) *Survey manual for tropical*
19 *marine resources*, 2nd. Edition. Australian Institute of Marine Sciences, Townsville,
20 363-376 pp.
21
- 22 Vermeij, M.J.A., Fogarty, N.D., Miller, M.W., 2006. Pelagic conditions affect larval
23 behavior, survival, and settlement patterns in the Caribbean coral *Montastrea*
24 *faveolata*. *Marine Ecology Progress Series* 310, 119-128.
25

- 1 Ward, S., 1995. The effect of damage on the growth, reproduction and storage of
2 lipids in the scleractinian coral *Pocillopora damicornis* (Linnaeus). Journal of
3 Experimental Marine Biology and Ecology 187, 193-206.
- 4
- 5 Woodley, J.D., Chornesky, E.A., Clifford, P.A., Jackson, J.B.C., Kaufman, L.S.,
6 Knowlton, N., Lang, J.C., Pearson, M.P., Porter, J.W., Rooney, M.C., Rylaarsdam,
7 K.W., Tunnicliffe, V.J., Wahle, C.M., Wulff, J.L., Curtis, A.S.G., Dallmeyer, M.D.,
8 Jupp, B.P., Koehl, M.A.R., Neigel, J., Sides, E.M., 1981. Hurricane Allen's impact on
9 Jamaican coral reefs. Science, 214, 749-755.

1 Legends to Figures.

2

3 Fig. 1. Coral reef sites in Southern Belize. The Sapodilla Cayes Marine Reserve
4 (SCMR), in dark grey shading to the left of the figure, comprises the southern end of
5 the MesoAmerican Barrier Reef, and includes Seal Cay, Frank's Cay, Nicholas Cay,
6 Hunting Cay and Lime Cay, where the SCMR sites were located. The Port Honduras
7 Marine Reserve (PHMR), in dark grey shading to the right of the figure, is close to the
8 coast near Punta Gorda Town. The PHMR sites were c. 1-3 km SW of South Snake
9 Cay. SCMR sites were: Mantas garden (N16° 09.614' W88° 14.823'), Franks I (N16
10 08.173' W88 20.113'), Franks II (N16° 08.188' W88° 20.087'), Seal Cay (N16° 10.537'
11 W88° 19.960'), Nicholas Cay (N16° 06.661' W88° 15.430'), and Protected I site (N16°
12 06.769' W88° 16.589'); PHMR sites were: South Snake Cay (N16° 10.550' W88°
13 33.815'), and Barracuda Bank (N16° 09.679' W88° 34.647'). North is to the top of the
14 page.

15

16 Fig. 2. Estimated recruitment dates for non-branching corals.

17 a, estimated recruitment dates for all 523 non-branching corals at the SCMR and
18 PHMR sites. Solid arrows show the years of hurricanes which impacted the area,
19 with their names (the hurricane in 1931 had no name); dotted line arrows show the
20 years where tropical storms impacted the area.

21 b, Histogram showing significant differences in non-branching coral recruitment in
22 years when hurricanes impacted the area ($p < 0.005$ for PHMR, $p < 0.05$ for SCMR)
23 than in years when no hurricanes impacted the area.

1 Figure 1

2

1 Figure 2a

2

1 Figure2b

2