2XKUH@ $@QKD R D@QKX NARDQU@SHNMR TONM "@QHAAD@M reefs describe a forgotten world. Caribbean cor- al reefs have suffered massive losses of corals RHMBD SGD D@QKX R CTD SN @ VHCD Q@MFD NE GT- man impacts including explosive human popula- SHNM FQNVSG NUDQjRGHMF BN@RS@K ONKKTSHNM FKNA@K V@QLHMF @MC HMU@RHUD RODBHDR 3GD BNMRDPTDMB- es include widespread collapse of coral popula- SHNMR HMBQD@RDR HM K@QFD RD@VDDCR L@BQN@KF@D outbreaks of coral bleaching and disease, and fail- ure of corals to recover from natural disturbances RTBG @R GTQQHB@MDR K@QL ADKKR VDQD RDS NEE AX SGD OTAKHB@SHNM HM SGD INTQM@K *Science* that live coral cover had been reduced from more than HM SGD R SN ITRS SNC@X 3GHR CQ@L@SHB decline was closely followed by widespread and RDUDQD BNQ@K AKD@BGHMF HM VGHBG V@R HM S 8¡Žîíí îÿì P°à € Moreover, two of the formerly most abundant species, the elkhorn coral BQNONQ@ O@KL@S@ and staghorn coral *Acropora cervicornis*, have been @CCDC SN SGD 4MHSDC 2S@SDR $MC@MFDQDC 2ODBHDR

If this were true, understanding why some reefs are healthier than others would provide an es-

and atolls. Geographic coverage was uneven, re-
kDBSHMF OQHL@QHKX SGD LNRS RSTCHDC RHSDR VHSG SGD
most easily accessible data. Only total coral cover was recorded, with no attempt to assess the fates of different coral species. Nor was there any attempt to compile records of macroalgae, sea
TQBGHMR @MC jRGDR SG@S @QD VDKK JMNVM SN G@UD
RHFMHjB@MS DBNKNFHB@K HMSDQ@BSHNMR VHSG BNQ@KR

We addressed these methodological problems by a detailed analysis of the status and trends of reef communities at distinct reef locations throughout the wider Caribbean. We also compiled essential metadata on the nature of the reef environment, depth, and history of human population growth,

locations and data sets reduces this estimate to N E @ M C 3 G D R @ L D V @ R S Q T D E
$ U D M S G H R L N abundant elkhorn and staghorn Acropora that be-
j M D C L D @ M H R G H F G D Q S G @ M S G D C B K H M H M F K S G D R S G D L @
D R S H L @ S D N E B N U D Q - D U D the sea urchin *Diadema antillarum* in 1983–84 (present means
C D B K H M D C @ S S G Q D D P T @ Q S D Q R N E S G D B D M S T Q X greatest decline (Gardner et al. 2003; Côté et al. 2005)
greatest losses for locations that were surveyed
earliest and for the longest time.

U D Q @ F D B N Q @ K B N U D Q E N Q @ K K K N B @ S H N M R V H S G B N Q @ K
C @ S @ C D B K H M D C E Q N L S N S N
over the three successive time intervals, but the
disparity among locations was great. In contrast,
L @ B Q N @ K F @ K B N U D Q H M B Q D @ R D C E Q N L S N
A D S V D D M @ M C G D K C R S D @ C X A T S V H S G
even greater disparity among locations since
3 G D O @ S S D Q M R V D Q D R H L H K @ Q E N Q S G D K N B @-
tions with coral data from all three intervals high-
K H F G S D C A X B H Q B K D R H M % H F 3 G D R D N O O N R H S D S Q D M C R
in coral and macroalgal cover constitute a large
and persistent Caribbean phase shift from coral
dominated to macroalgal dominated communi-
S H D R S G @ S G @ R O D Q R H R S D C E N Q X D @ Q R % H F R @ M C
@ O @ S S D Q M @ K R N R S Q N M F K X R T O O N Q S D C A X N Q C H M @ S H N M
analyses of benthic community composition.

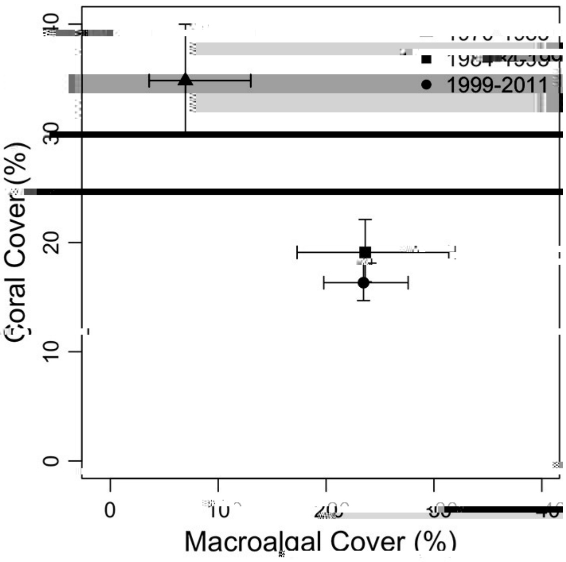


FIGURE 3. Large-scale shifts from coral to macroalgal community
G R P L Q D Q F H V L Q F H W K H H D U O \ V 6 \ P E R O V D Q G F R Q u G H Q F H L Q W H U Y D O V
represent means and standard deviations for 3 time intervals that take
into account variability due to location, and datasets using a mixed
modeling framework.

The greatest overall changes in coral and mac-
Q N @ K F @ K B N U D Q N B B T Q Q D C A D S V D D M @ M C
after which there was little overall change at the
F Q D @ S L @ I N Q H S X N E K N B @ S H N M R D W B D O S E N Q O K @ B D R L N R S
strongly affected by the extreme warming events

Caribbean species. Taxonomic diversity and ecological redundancy are low and the potential for QDITUDM@SHNM EQNL NSGDQ QDFHNMR HR DRRDMSH@KKX MHK Caribbean species also had no evolutionary experience for dealing with exotic species and disease before the advent of people.

We focused on potential anthropogenic drivers of decline for which there were data for meaningful comparisons. Drivers were treated separately for ease of analysis and discussion, but they are inextricably linked. In particular, coral disease is a complex and poorly understood symptom of several forms of human disturbance rather than a direct driver of change. Thus disease is treated in relation to several different drivers including introductions of alien species, ocean warming, coastal stronger for evaluating effects of human popula- SHNM HMBQD@RD NUDQjRGHMF cause there are more data, and less so for coastal pollution and invasive species.

FIGURE 5. Examples of mass tourism in the Caribbean. (A) Large cruise ships with thousands of passengers arrive every day in the Caribbean, shown here is St. Thomas, the US Virgin Islands (Source: Calyponte, Wikipedia). (B) Numerous hotel resorts offer ever more tourists the opportunity to stay in the Caribbean Sea, as here at Cancún Island, Mexico (Source: Foto Propia, Photo by Mauro I. Barrera, Wikipedia). (C) High density of tourists line South Beach, Miami, Florida (Source: Photo by Marc Averette, Wikipedia).

Tourism is the lifeblood of many Caribbean nations %HF 'NVDUDQ NTQ DUHCDMBD CDLNMRSQ@SDR SG@S extremely high densities of both tourists and residents are harmful to reefs unless environmental protections are comprehensive and effectively enforced. Unfortunately, this is only rarely the case. -TLADQR NE UHRHSNQR ODQ RPT@QD JHKNLDSDQ ODQ XD@Q Q@MFD EQNL @ KNV NE HM SGD !@G@L@R SN @M @R- SNTMCHMF @S 2S 3GNL@R KK KNB@SHNMR VHSG LNQD SG@M SGD LDCH@M U@KTD NE UHRHSNQR ODQ RPT@QD JHKNLDSDQ ODQ XD@Q G@UD KDRR SG@M SGD LD- CH@M U@KTD NE BNQ@K BNUDQ DWBDOS ENQ !DQLTC@ VHSG BNUDQ @MC &Q@MC "@XL@M VHSG The exceptional situation at Bermuda most likely

QDkDBSR OQNFQDRRHUD DMUHQNMLDM OK@MMD RHLHK@Q SNTQHRLF @MC SGD HME PTHQDC SN L@JD SGDL VNQJ .SGDQVH ful environmental costs of runaway tourism seem to be inevitable.

QSHR@M@K jRGHMF ENQ RTARHRSDMB "@QHAAD@M DBNMNLHDR ATS SGD BN G@UD ADDM B@S@RSQNOGHB ENQ BNQ@ caused steep reductions in herbivores, especially QP I00 @ 0 F

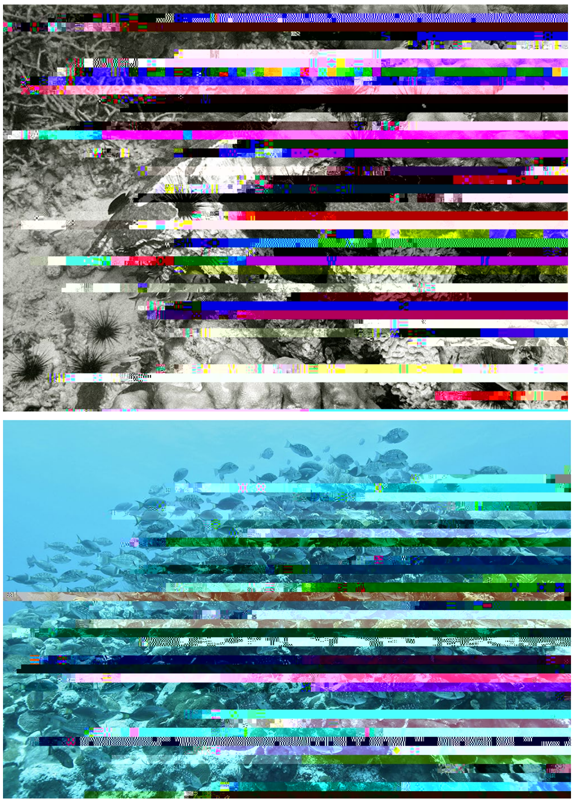
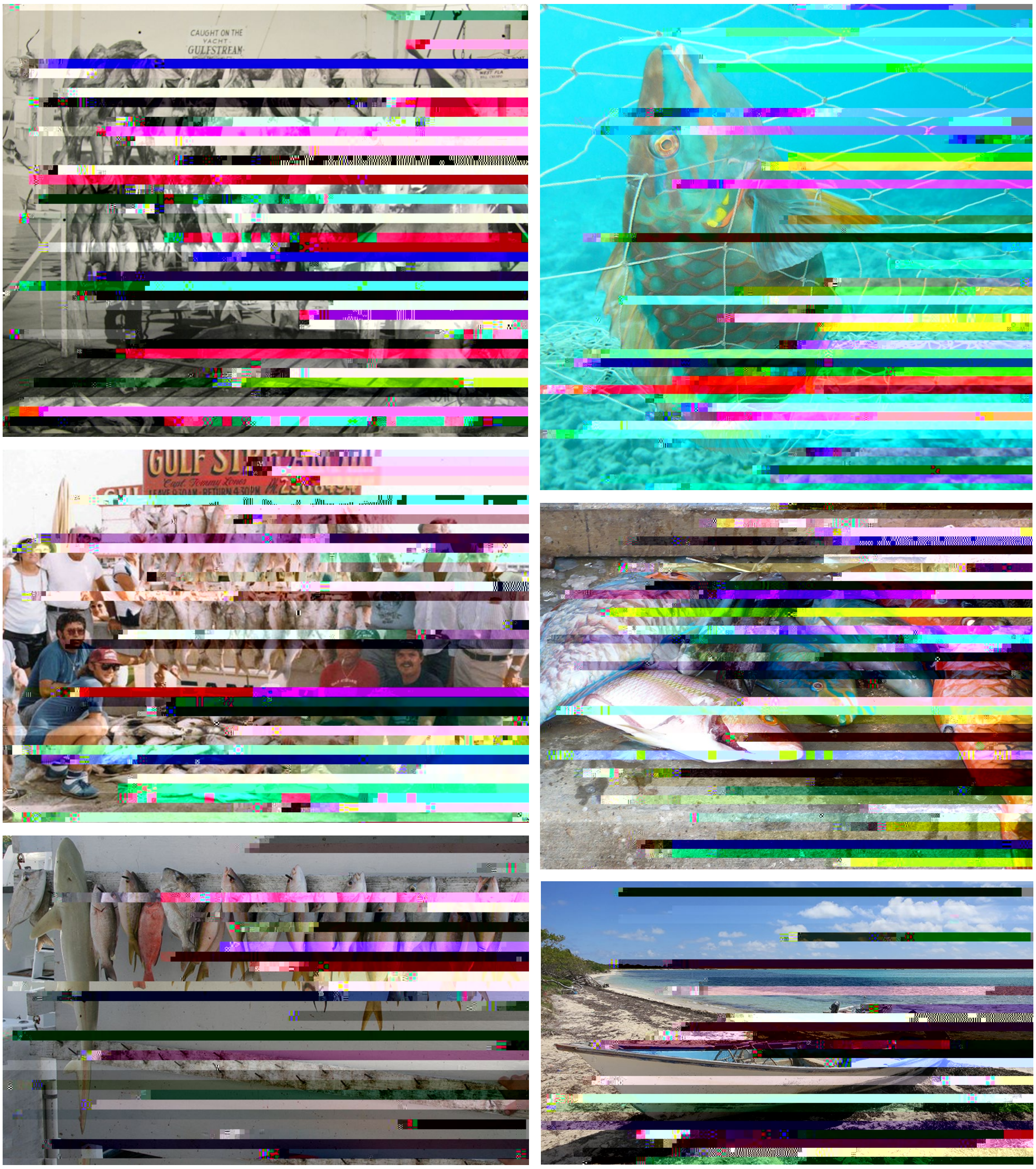


FIGURE 6. Formerly abundant grazers on Caribbean reefs. (A) Dense aggregation of the sea urchin Diadema antillarum on the west forereef at Discovery Bay, Jamaica in about 10 meters a year before the massive die-off in 1983/1984 (Photo by Jeremy Jackson). (B) Large school of Stoplight Parrotfish Sparisoma viride on the south shore



),*85(2YHUuVKLQJ VHYHUHO\ UHGXFHG uVK ELRPDVV DQG GLYHUVLW\ LQ WKH &DULEE

V@SDQ SQ@MRO@QDMBX RSDDOKX CD

Limited comparative data for water transpar- ency based on secchi disk observations at three

years at Carrie Bow Cay in Belize due to huge increases in agriculture and coastal development

" 1(".,/ RHSDR "@QHAAD@M

/QNCTBSHUHSX /QNFQ@L AX 4-$2" .%R

SDQ PT@KHSX HR CDBKHMHMF /HM F@TDQ@R

ricultural and coastal development. In particular,

BNMSQ@RS V@SDQ PT@KHSX HLOQNUD

Coral disease has been linked to excessive organic pollution but the data are spotty and limited in scope. In general there is a pressing need for more systematic and extensive monitoring of wa- SDQ PT@KHSX SGQNTFGNTS SGD VHCDQ "@QHAAD@M

.TQ jQRS @M@KXRDR VDQD A@RDC NM SGD 1DDEA@RD compilation of extreme bleaching events that RGNVDC MN RHFMHjB@MS QDK@SHNMRGHO ADSVDDM SGD numbers of extreme events per locality and coral cover at locations across the wider Caribbean, Gulf of Mexico and Bermuda. Because of the RTAIDBSHUHSX NE RTBG AKD@BGHMF @RRDRRLDMSR GNV- ever, we obtained data for degree heating weeks

#'6R ENQ @KK KNB@KHSHDR VHS -. "NQ@K 1DDE 6@SBG

We then used these data to assess the effects NE SGD @MC @KK DC S

the analysis to include only localities that experi-
DMBDC @S KD@RS #'6R ,NQDNUDQ SGD FQD@SDRS
losses in coral cover occurred at reef locations
VHSG KDRR SG@M #'6R

We caution that our results do not mean that extreme heating events are unimportant drivers of coral mortality due to coral bleaching and disease,
@R SGDX BKD@QKX G@UD ADDM HM SGD 425(/TDQSN 1HBN
%KNQHC@ *DXR @MC DKRDVGDQD ,NQDNUDQ HMBQD@R-
ingly severe extreme heating events will pose an even greater threat to coral survival in future decades. But our results do belie any regionally consistent effects of extreme heating events up to now and strongly imply that local stressors have been the predominant drivers of Caribbean coral decline to date.

/NSDMSH@KKX CDKDSDQHNTR DEEDBSR NE NBD@M @BHCH-

Because of their isolation for millions of years, and
AX @M@KNFX SN SGD E@SDR NE -@V@HH@M R@MCQ@VBGDR
SGDHQ jQRS BNMS@BS VHSG $TQNOD@MR
cies should be exceptionally prone to the impact
NE HMSQNCTBDC CHRD@RDR
case. We know of no examples of the virtual elimination due to disease of any marine species through-
NTS SGD DMSHQD DWSDMS NE SGD (MCH@M NQ /@BHjB NBD@MR
comparable to the demise of Caribbean Diadema and Acropora. This interpretation is also consistent
VHSG SGD @OO@QDMS K@BJ NE @MX L@INQ DMUHQNMLDMS@K
RGHES HM SGD R SG@S LHFGS G@UD SQHFFDQDC SGD NTS-
break of disease. Most importantly, the emergence of these diseases occurred many years before the
jQRS QDONQSDC DWSQDLD GD@SHMF DUDMSR

It would be possible to test this introduced species hypothesis for WBD since the pathogen is known
@MC @U@HK@AKD ENQ #- RDPTDMBHMF (S L@X @KRN AD
possible for Diadema even though the pathogen is unknown by genetic analysis of entire frozen specimens of Diadema that died from the disease. This is not an entirely academic exercise: the two pivotal events in the demise of most Caribbean reefs are as much a mystery today as they were when they
jQRS NBBTQQDC NQ LNQD XD@QR @FN

Outbreaks of Acropora and Diadema diseases
HM SGD R @MC D@QKX R NUDQONOTK@SHNM
HM SGD ENQL NE SNN L@MX SNTQHRSR @MC NUDQjRG-
ing are the three best predictors of the decline in
"@QHAAD@M BNQ@K BNUDQ NUDQ SGD O@RS NQ LNQD

years based on the data available. Coastal pol-
KTSHNM HR LNQD HLONQS@MS SG@M DUDQ
There are still too little data to tell. Increasingly
warming seas pose an ominous threat but so far
extreme heating events have had only localized
effects and could not have been responsible for

NUDQjRGHMF BN@RS@K ONKKTSHNM DWOKNRHNMR HM tourism, and extreme warming events that in combination have been particularly severe HM SGD MNQSGD@RSDQM "@QHAAD@M @MC %KNQHC@ Keys where extreme bleaching followed by outbreaks of coral disease have caused the greatest declines.

Our results contradict much of the rhetoric about the importance of ocean warming, disease, and hurricanes on coral reefs and emphasize the critical importance of historical perspective for coral reef management and conservation. The threats NE BKHL@SD BG@MFD @MC NBD@M @BHCHjB@SHNM KNNL increasingly ominously for the future, but local stressors including an explosion in tourism, over jRGHMF @MC SGD QDRTKSHMF HMBQD@RD HM L@BQN@KF@D G@UD ADDM SGD L@INQ CQHUDQR NE SGD B@S@RSQNOGHB decline of Caribbean corals up until today.

What this means is that smart decisions and actions on a local basis could make an enormous difference for increased resilience and wellbeing of Caribbean coral reefs and the people and enterprises that depend upon them. Thus, four ma-INQ QDBNLLDMC@SHNMR DLDQFD EQNL SGHR QDONQS

$GRSW UREXVW FRQVHUYDWLRQ DQG ðVKHULHV management strategies that lead to the QDRSNQ@SHNM NE O@QQNSjRG ONOTK@SHNMR HMBKTC-HMF SGD KHRSHMF NE SGD O@QQNSjRG HM QDKDU@MS @M-MDWDR NE SGD /QNSNBNK BNMBDQMHMF 2ODBH@KKX /QNSDBSDC QD@R @MC 6HKCKHED 2/ 6 OQNSN-BNK NE SGD 4-$/ "@QHAAD@M $MUHQNMLDMS /QNFQ@LLD QDBNLLDMC@SHNM SN SGHR DEEDBS V@R O@RRDC TM@MHLNTRKX @S SGD .BSNADQ International Coral Reef Initiative Meeting in !DKHYD RDD !NW

Simplify and standardize monitoring of Caribbean reefs and make the results available on an annual basis to facilitate adaptive management.

Foster communication and exchange of information so that local authorities can ben-DjS EQNL SGD DWODQHDMBDR NE NSGDQR DKRDVGDQD

Develop and implement adaptive legislation and regulations to ensure that threats to coral reefs are systematically addressed,

Accordingly, the International Coral Reef Initiative urges Nations and multi-lateral groupings of the wider Caribbean to:

Adopt BNMRDQU@SHNM @MC jRGDQHDR L@M@FDLDMS-RSQ@SDFHDR QNSjRG ONOTK@SHNMR @MC RN QDRSNQD SGD A@K@MBD ADSVD healthy coral reefs;

Maximise the effect of those management strategies by incorporating necessary resources for outreach, compliance, enforcement and the examination of alternative livelihoods for SGNRD SG@S L@X AD @EEDBSDC AX QDRSQHBSHNMR NM SGD S@J

Consider KHRSHMF SGD O@QQNSjRG HM SGD MMDWDR NE SGD 2/ 6 /Q SN GHFGKHFGSHMF SGD HRRTD NE QDDE GDQAHUNQX HM QDKDU@

Engage with indigenous and local communities and other stakeholders to communicate the ADMDjSR NE RTBG RSQ@SDFHDR ENQ BNQ@K QDDE DBNRXRSDLR @MC BNLLTMHSHDR DBNMNLX