Incorporating Climate Change Projections into Caribbean Fisheries Management

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ABSTRACT

Concerns over the socio-economic impacts of observed and projected changes of climate have been high on the research agendas of scientists the last several decades. According to the Intergovernmental Panel on Climate Change, the recent observed warming is largely human-induced, and the trend will continue at least into the next century owing to 'thermal inertia', directly related to the concentration of greenhouse gases already emitted to the atmosphere (IPCC, 2001, 2007). While there is a dearth of research on the specific effects of climate change on commercial and artisanal fisheries in the Caribbean, valuable insights can be gleaned from observations and projections in other jurisdictions. In contrast with some projections in middle and higher latitudes, the consequences of climate change on Caribbean fisheries are expected to be mostly negative. Adverse impacts on regional fisheries are likely to manifest themselves through habitat alteration and loss, reduced abundance and diversity, and possibly shifts in distribution induced by changes in ocean currents. In light of these projections, stakeholders in the regional fishing industry might wish to give greater credence to the challenges posed by climate change and climate variability than currently appears to be the case. Appropriate response strategies may not require radical changes in current approaches to management, but rather more effective implementation of existing and proposed arrangements.

KEYWORDS: Climate, change, variability, fisheries, management

Incorporando Proyecciones de Cambio Climático en el Manejo de la Pesca del Caribe

Preocupaciones sobre los impactos socio-económicos de cambios climáticos observados y proyectados han estado alto en las agendas de investigaciones de los científicos durante las décadas pasadas. De acuerdo con el Panel Intergubernamental de Cambio Climático, el calentamiento que se esta observando recientemente en gran parte es inducido por los humanos, y este tendencia continuara por lo menos hasta el próximo siglo debido a "inercia térmica", relacionada directamente a la concentración de gases del efecto invernadero que ya han sido emitidos a la atmósfera (IPCC, 2001, 2007). Aunque existen escasas investigaciones relacionadas a los efectos del cambio climático en la pesca artesanal y comercial en el Caribe, se ha obtenido un entendimiento invaluable producto de las observaciones y proyecciones en otras jurisdicciones. En contraste con algunas proyecciones en las latitudes medias y altas, se espera que las consecuencias del cambio de clima en la pesca del Caribe sean primordialmente negativas. Es probable que los impactos adversos en la pesca regional se manifiesten vía alteración y perdida de hábitat, diversidad y abundancia reducida, y posibles variaciones en la distribución inducida por cambios en las corrientes oceánicas. En vista de estas proyecciones, los stakeholders dentro de la industria regional de pesca probablemente deseen brindar mayor credibilidad a los desafíos presentados por el cambio climático y variabilidad climática del que al parecer se le esta brindando actualmente. Respuestas estratégicas adecuadas quizás no impliquen cambios radicales en el enfoque de manejo actual, sino una implementación más efectiva de acuerdos propuestos y existentes

PALABRAS CLAVES: Cambio climático, variabilidad climática, manejo de pesquerías

Incorporation des Projections des Changements Climatiques a la Gestion des Pêches dans la Caribe

L'intérêt de la recherche scientifique pour les impacts socio-économiques des changements climatiques s'est accru ces dernières décades. Selon le groupe de Conseil Intergouvernemental sur le changement climatique, le réchauffement récent observé est largement dû à l'homme, et la tendance va continuer au moins dans le nouveau siècle grâce à l' « inertie thermique » liée à la concentration en gaz à effet de serre déjà émis dans l'atmosphère (IPCC, 2001, 2007). Bien qu'il existe une pénurie de recherches sur les effets spécifiques du changement climatique sur les pêcheries, des idées valables peuvent être glanées des observations et des projections dans d'autres domaines. En contraste avec certaines projections concernant les latitudes moyennes et hautes, on s'attend à ce que les conséquences du changement climatique sur les pêcheries soient surtout négatives. Des impacts défavorables sur les pêcheries régionales sont susceptibles de se manifester à travers la perte et l'altération des habitats, la réduction de l'abondance et de la diversité et des changements possibles dans la distribution provoqués par des variations des courants océaniques. A la lumière de ces projections, les acteurs économiques de l'industrie de la pêche régionale devraient souhaiter donner un plus fort crédit aux défis posés par le changement climatique et sa variabilité. Des stratégies de réponses appropriées pourraient ne pas requérir de changements radicaux dans les approches courantes de gestion, mais plutôt une mise en œuvre plus efficace d'aménagements déjà proposés et existants.

MOTS CLÉS: Changement climatique, pêcheries, gestion

THE GLOBAL CONTEXT

Global mean air temperatures have increased by approximately 0.7^{0}C during the 100 year period 1906 - 2005. For the next two decades a warming of about 0.2°C per decade is projected for a range of GHG emission scenarios (IPCC, 2007). In addition, during the 20th Century global sea levels rose at a rate approximately 10 times faster than the average rate for the previous 3000 years (Ibid.). Outputs from a suite of climate models indicate that human-induced warming (approx. 0.1°C per decade) and incremental sea level rise would continue for centuries due to the level of inertia in the climate system, even if greenhouse gas concentrations were to be stabilized at year 2000 levels (Ibid.).

Stakeholders in the fisheries sector should equally be concerned about the post-1900 increases in frequency, intensity and persistence of warm (El Niño) phases of El Niño Southern Oscillation (ENSO), as well as an observed trend of increasing sea-surface temperatures. Before the end of the current Century mean global sea-surface temperatures are expected to be approximately 1.0 - 2.0^{o}C higher than the 1990 mean (IPCC 2001). In the specific case of the tropical oceans, temperatures are projected to be 2^{o}C by the 2050s and 3^{o}C higher by the 2080s, relative to the same 1990 baseline (Lal *et al*. 2002). The link between ocean warming, El Niño occurrences and coral bleaching is now well-established, and there is considerable observational evidence to show that the most intense bleaching events since 1900 have all occurred in those years when the El Niño signal has been strongest (Glynn 1984, Goreau *et al*. 2000, Wilkinson 2000, McWilliams *et al*. 2005)

Ever since publication of the First Assessment Report of the Intergovernmental Panel on Climate Change in 1990, a large volume of literature has emerged on the observed and projected impacts of climate change and climate variability on terrestrial and marine habitats, and their associated assemblages of flora and fauna. The literature provides an abundance of evidence of a wide spectrum of responses from the species to the community level in all latitudes, and documents observed as well as projected climate change impacts on all socio-economic sectors, including fisheries (IPCC 1990, 2001, 2007; Walther *et al.* 2002, Edwards and Richardson 2004, Winder and Schindler 2004, Garpe *et al*. 2006). Regrettably, focused investigations on the impacts of climate change and climate variability on Caribbean fisheries has lagged considerably behind the work conducted in other regions. However, notwithstanding the dearth of region-specific research, there is both an opportunity and a need for Caribbean fisheries stakeholders to build upon the existing global knowledge base, as they become increasingly confronted with the inevitability of designing mitigation and adaptation strategies to global climate change.

LINKING CLIMATE CHANGE AND FISHERIES: WHAT DO WE KNOW?

While there is a need for considerably more research especially at the species level, there already exists a good generic understanding of the *potential* impacts of climate change and climate variability on key factors and processes that influence recruitment, abundance, migration, and the spatial and temporal distribution of many fish stocks. For instance, the consequences of greenhouse gas emissions on the seasonality and intensity coastal upwelling and the implications for fish and other marine organisms has occupied the attention of scientists for many decades (Bakun 1990, Wiafe *et al*. 2008). This is well demonstrated in the case of the California Current, where both intensification of upwelling and seasonality changes in the phenomenon have been documented (Diffenbaugh *et al*. 2004). The impact of CO_2 -induced warming is equally well documented for the upwelling region of the Gulf of Guinea, where zooplankton biomass decreased by approximately 6.33 ml per 1000 m^3/year between 1969 and 1992, in phase with sea surface warming (Wiafe *et al*. 2008). Coincidentally, *Calanoides carinatus*, a crustacean whose appearance is observed only in the major upwelling season (July - September) and known to be highly sensitive to temperatures > 23°C, also decreased in abundance (Wiafe op. cit). Similar observations have been noted at various other upwelling locations including South Africa (Schumann, 1999), Northwest Africa (McGregor *et al*. 2007), Chile (Arcos *et al*. 2001, Escribano and Schneider 2007) and India (Krishna 2008).

Equally well documented is a noticeable poleward shift in the range of various marine species, in response to ocean warming both at surface and at depth (Fields *et al*. 1993, Sagarin *et al*. 1999). Murawski (1993) has shown that a number of pelagic species including Atlantic mackerel and Atlantic herring tend to migrate poleward by approximately 0.5 - 0.8 degrees of latitude for every1^{0}C increase in mean sea surface temperature. Similarly, Perry et al. (2004) have demonstrated that almost two-thirds of exploited and non-exploited North Sea fishes have shifted either poleward or to greater depth as a response to elevated sea water temperature over the last 25 to 30 years. This is further supported by the findings of Field *et al*. (2006) who documented a significant increase in the number of tropical and sub-tropical species of planktonic foraminifera in the California Current, but a decline in abundance of temperate and sub-polar species during the 20th Century. Barry *et al*. (1995) have also noted a northward shift in the range of eight 'southern' invertebrate fauna along the California coast between 1931 and 1994, when mean temperatures in the bay rose by 0.75°C.

These findings corroborate the conclusions of Roemmich and McGowan (1995), who had earlier noted an 80% decrease in macrozooplankton biomass off the coast of southern California since 1951. This was linked to ocean surface warming which exceeded 1.5°C in some localities, reduced upwelling and a smaller volume of inorganic nutrients to support the zooplankton population. These changes correlate well with 20th Century anthropogenic warming at depth, a phenomenon not manifested in earlier centuries. Similar findings are documented for the northeast Atlantic where a decline in phytoplankton abundance has accompanied sea surface warming, with the reverse occurring in cooler regions to the north (Richardson and Schoeman 2004). It is projected that with the continued warming trend, the spatial distribution of primary and secondary pelagic production would be affected to the extent that it would contribute to further depletion of north Atlantic fish stocks.

The sensitivity of tuna stocks to temperature changes, especially during ENSO, and the spatial variation in catch has been studied in the Pacific, and Maldives in the Indian Ocean. In the Pacific, there is a tendency for both skipjack and yellow fin tuna to move eastward during the El Nino phase, resulting in a significantly reduced catch. This is associated with the zonal displacement of the Pacific '*warm pool*' where these species are dominant (Lehodey *et al*. 2003). In the case of the Maldives, skipjack catches tend to decline in El Nino years, while the yellow fin harvest increases. Contrastingly, during La Nina years, skipjack catches increase, while there is a decrease in other tuna species (MOHA 2001). Overall, the IPCC (2007) projects that climate change is likely to lead to migration and ultimately decline of these tuna stocks.

Research indicates that climate change will also lead to other more complex biological changes and responses in marine organisms, including fish. For example, it has been shown that patterns of larval transport and population dynamics are being affected by observed changes in ocean circulation. It is also suggested that climatic impacts on a few '*leverage species*' could ultimately lead to far-reaching community level changes (Harley *et al*. 2008). In addition, there is evidence which suggests that the development and survival of many fish species may be impacted more by changes in ocean chemistry (linked to climate change) than by elevated sea surface temperatures *per se*. While the effects of such changes are not yet fully understood, early evidence suggests that the impacts on fisheries will be overwhelmingly negative. Moreover, these climate-induced changes are likely to be exacerbated by other well-documented anthropogenic stresses, including overfishing (Harley *et al*. 2008).

WHAT ARE THE KEY CLIMATE CHANGE PROJECTIONS OF RELEVANCE TO THE CARIBBEAN FISHERIES SECTOR?

Apart from the obvious implications of the global observations highlighted above, there are additional avenues via which climate change will impact the Caribbean fisheries sector, directly and indirectly. The discussion that follows is not intended to be exhaustive, it merely seeks to highlight issues of relevance to the region's fisheries sector for which sound, scientific consensus is emerging. It is also anticipated that the analysis will contribute to the development of a clearer understanding of the range of climate-related risks to which the sector will be exposed.

Of critical significance is the fact that the pattern of observed temperature changes in the region is consistent with the global trend (IPCC 2007, Hayes and Goreau 2008). Regional temperatures increased in the 20th Century with the 1990s being the warmest decade since 1900. Outputs from a suite of global climate models (GCMs) suggest that surface air temperatures in the Caribbean will continue to increase in the present Century by between 0.5^0 - $1.^0$C during the period 2010 - 2039, 0.8^0 - 2.5^0C in the decades 2040 - 2069 and 0.94^0 - 4.8^0C between 2070 and 2099. Recent climate model runs for the Eastern and Southern Caribbean show that a similar trend in sea surface temperatures can also be expected. This is shown in figures 1 and 2 which are outputs from the HADCM 3 and ECHAM GCM, downscaled to 25 km resolution using the PRECIS model. These results clearly suggest that that sea-surface temperatures will not only increase during the summer (JJA), but also during the traditional 'cool' season (DJF). Of equal interest is the indication that both the diurnal and seasonal temperature ranges will also decrease. This has particularly severe implications for Caribbean corals which would, under such circumstances, be consistently exposed to even higher minimum and maximum temperatures that at present.

There is strong support from the observational records that elevated sea surface temperatures are a primary cause of coral bleaching. The most severe episodes in the past have coincided with years when the El Niño signal was strongest, for instance in 1983, 1985, 1997/98, 2005/2006. (Glynn 1984, Hoegh-Guldberg 1999, Goreau *et al*. 2000). In the 1997/98 event, more 95% of Pacific corals were bleached, and approximately 25 - 30% in Caribbean (Wilkinson 2000). The most recent intense bleaching episode in the Caribbean occurred during the summer of 2005, when bleaching occurred in an area extending from Mexico in the north, to Tobago in the south. A detailed case study of the event at Barbados revealed that throughout the summer, sea surface temperatures were consistently between 1^0 - 2^0 C above seasonal maxima, and all near-shore and offshore habitats were affected (Oxenford *et al.* 2008). The situation in Barbados was not unique to the Eastern Caribbean, since many other islands also reported significant bleaching. Certainly, fishers will find no comfort in these events, particularly since they are projected to become more frequent in the future.

Another emerging issue that could be potentially worrisome for fisheries stakeholders is the observed and projected change in the level of acidity of the world's oceans, associated with increasing anthropogenic emissions of CO_2. Research has shown that the world's oceans have become approximately 30% more acidic (i.e. a reduction in pH from 8.2 to 8.1 units) since 1750 - the start of the Industrial Revolution (IPCC, 1990, 2001, 2007). Although the effects on marine organisms are not yet fully understood, ocean acidification is expected to be a limiting factor in the development of corals and other organisms, which use carbonate ions in sea water to build calcium carbonate shells and exoskeletons. With rising CO_2 emissions, more CO_2 is absorbed by the oceans, sea water becomes more acidic by stripping out carbonate ions, thus making it more difficult for organisms to form shells (Kleypas *et al*. 2005; Fabry *et al.* 2008). With global CO_2 emissions continuing to increase at a rapid rate, the threat to reef habitats and associated fauna, including fish assemblages, will become more pronounced. Since the reef fishery constitutes a vital component of small-scale activity, this sector of the industry is likely to be most affected.

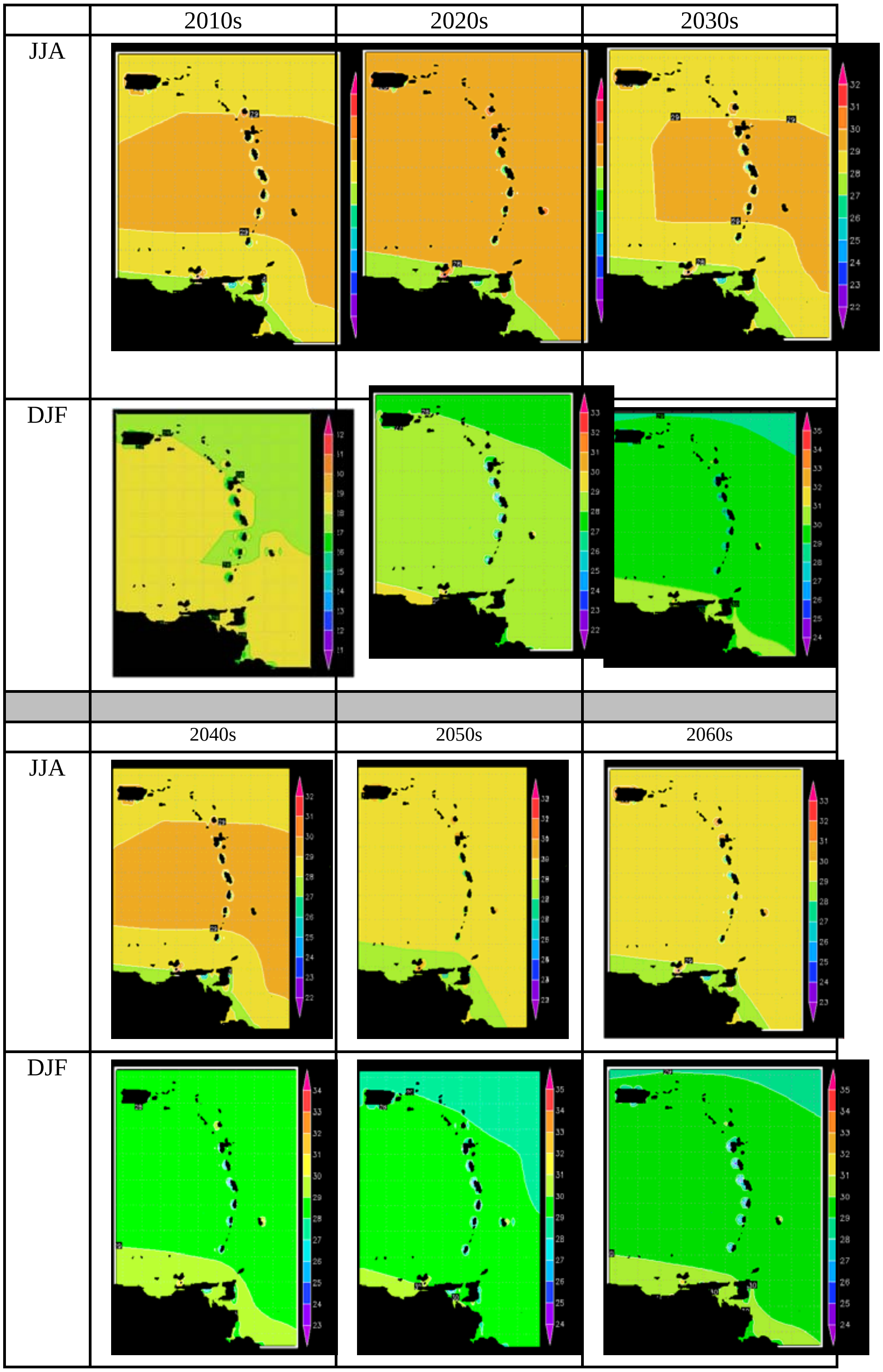

Figure 1. Modeled Decadal Sea Surface Temperatures - Eastern Caribbean

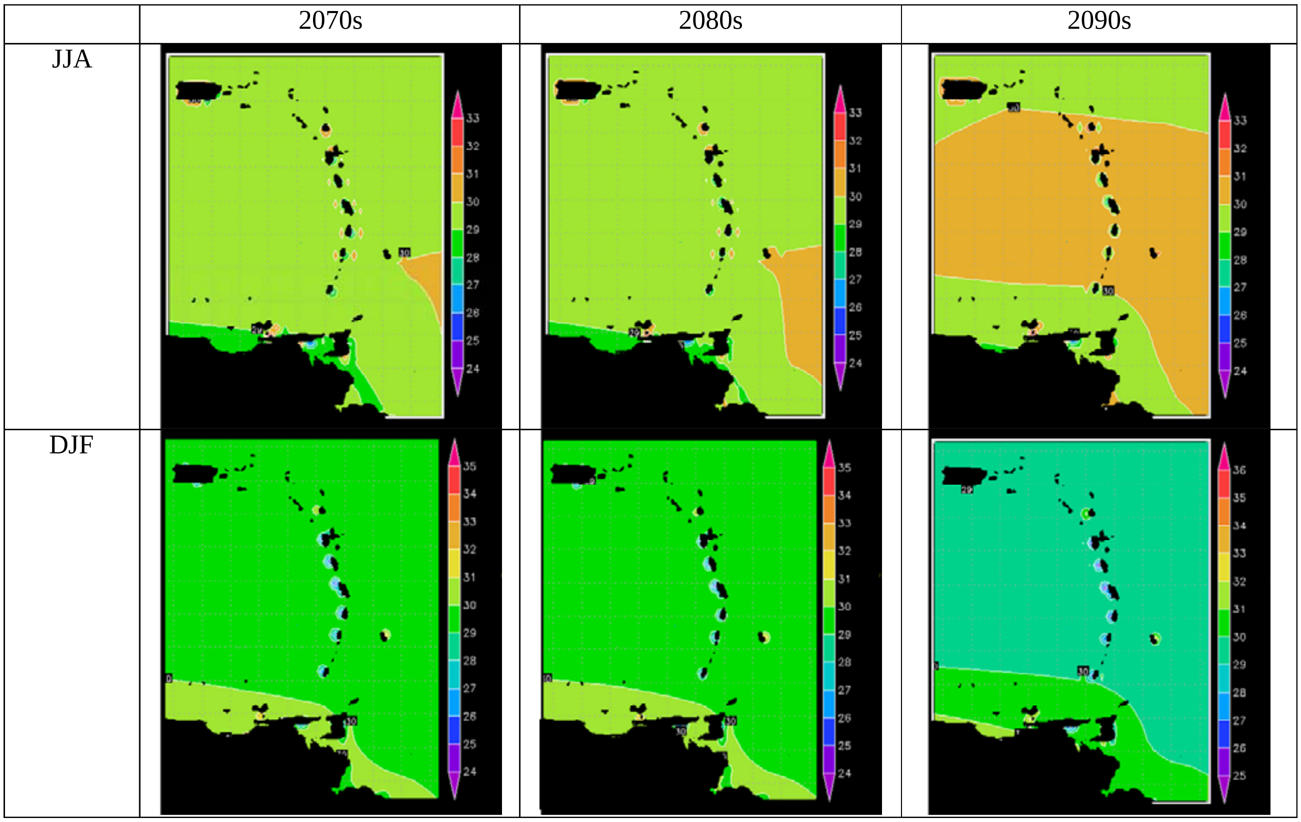

Figure 2. Modeled Decadal Sea Surface Temperatures - Eastern Caribbean

While there is as yet no clear indication that tropical cyclones (hurricane) frequency will change, modeled data indicate that peak wind intensities are expected to increase by approximately 5-10% by the 2050s (Emanuel, 2006; IPCC, 2007). Moreover, of those systems that reach hurricane status, a greater number appears to be attaining a status of category 3 and above than in prior decades. For instance, in the first seven years of the present decade (2001-2010) eight category 5 hurricanes have already developed, compared with a total of twenty-three recorded between 1928 and 2000 (Table 1). In addition, it is already being hypothesized that these systems may be reaching high intensity over a shorter duration than previously observed. This is exemplified by hurricanes Wilma (2005) and Gustav (2008), which moved from tropical depression status to category 5 and 4 hurricanes in less than 24 hours. Should this become a trend, fishers will be faced with the prospect of having greatly reduced time frames for securing boats, gear and other equipment. Similarly, the expected increase in maximum wind speeds combined with currently projected increments of sea-level rise for the region, would amplify storm surge effects, and accelerate coastal erosion and loss. Apart from damage to equipment, critical infrastructure such as wharves, jetties and other fish landing sites would be at very high risk under this likely scenario.

(Note: Since official hurricane records have been kept, no category 5 systems have been identified prior to 1928.}

Table 1. Category 5 Atlantic Hurricanes, 2001-2007
Source: NOAA, 2008

Hurricane	Year	Maximum Winds, km/hr (mph)
Isabel	2003	266 (165)
Ivan	2004	266 (165)
Emily	2005	290 (180)
Katrina	2005	282 (175)
Rita	2005	290 (180)
Wilma	2005	298 (185)
Dean	2007	266 (165)
Felix	2007	266 (165)

VULNERABILITY OF CARIBBEAN SMALL-SCALE FISHERIES TO CLIMATE CHANGE

There is universal agreement that the vulnerability of any sector to climate change is a function of (a) the degree of exposure to the threat (b) the sector's sensitivity to the risk and (c) the capacity of the sector to cope with or adapt to the threat (IPCC 1995, 2001, 2007; FAO 2005). Any objective assessment of small-scale fisheries in the Caribbean's would conclude that exposure and sensitivity to the climate change threat are *high*, while adaptive capacity is *low* (see for example FAO 2005, Salas *et al.* 2007). Among the reasons for this conclusion are:

i) Observed and projected negative impacts (direct and indirect) on the sector, e.g. through habitat and ecosystem damage, e.g. bleaching of corals, additional stress on mangroves and seagrasses;
ii) Linkage between ocean warming as a *triggering mechanism* in the proliferation of harmful algal blooms and various diseases;
iii) Dependence of fisher folk on sector for employment, revenue generation and human well-being;
iv) In the Caribbean many fisher folk tend to reside in vulnerable, low-lying coastal areas which exposes their physical assets (e.g. boats, gear, homes) to climate-related events such as hurricanes, storm surge and sea-level rise;
v) While the sector has demonstrated considerable resilience to climate variability in the past, factors such as lack of consistent governmental, access to capital on reasonable terms, weak fisher folk organizations and consequently low bargaining power will compromise adaptation capacity in the future;

Lack of insurance and other institutional support to enable the sector to rebound in the aftermath of extreme events, which are projected to become more frequent and/ or intense in the future.

While the list of factors presented above is not exhaustive, it provides a reasonable indication of the issues confronting the fisheries sector in the Caribbean. Since it is widely anticipated that climate change will amplify these challenges, appropriate and timely interventions will be required in order to minimize the adverse effects on stakeholders. Some possible approaches are offered for consideration in the ensuing section of this paper.

HOW MAY THE CARIBBEAN FISHERIES SECTOR RESPOND TO CLIMATE CHANGE?

Like other sectors, the fishing industry in the Caribbean, in particular its small-scale sector, is already experiencing some of the negative impacts of anthropogenic climate change. Since elimination of the source of the problem is practically unachievable, adaptation is the only option. Given the range of impacts and challenges posed by global climate change, any meaningful response will inevitably require a suite of practical measures aimed, *inter alia*, at building resilience in the sector, exploiting available opportunities, and minimizing the economic and social dislocation of fishers. At the very minimum, the design of an adaptation package should reflect the status of the science, it should be flexible in order to benefit from new research findings, it should exploit the rich knowledge base of key actors i.e. the fishers, while at the same time being cost-effective, and socially and culturally acceptable to stakeholders.

It should be emphasized from the outset that adaptation must be regarded as a *process*, not a project. It should also be stressed that the process does not necessarily imply the abandonment of existing management practices and the implementation of new, high-cost strategies. While some new initiatives may be required, stakeholders may wish to begin the process by simply strengthening existing management structures and *mainstreaming* ‘adaptation thinking’ into these arrangements. Fortunately for the Caribbean, there is already a basic platform (e.g. legislation, advisory committees, a regional coordinating mechanism) in place which can be adjusted, as required, to accommodate sound adaptation practice.

First, there should be an ongoing commitment to implement those actions that will improve the resilience and, therefore, the sustainability of the sector (See for instance Charles 2003, IPCC 2007). In this regard, the strategy should be guided by pragmatism, so that the emphasis should be on activities over which countries have some control and which, if implemented, will have a positive impact. Thus, while the region can do little to reverse the trend of global greenhouse gas emissions and higher sea water temperatures, actions can be taken to improve the resilience of habitats and targeted species to the adverse effects of climate change. Such actions would include:

i) Strict enforcement of existing marine pollution control protocols and abatement of contamination from land-based sources,
ii) Reactivation and expansion of habitat protection and restoration programmes, and
iii) Control of non-sustainable practices such as overharvesting, and the use of inappropriate harvesting methods.

The benefits of applying good governance and *co-management* principles in the small-scale fisheries sector have been widely discussed in the literature (Pomeroy and Berkes 1997, McConney *et al.* 2003). Governance and co-management systems that are based, *inter alia*, on an understanding of ecosystem health and thresholds, partnership, stakeholder inclusiveness, equity, and sustainable livelihoods should also be regarded as vital elements of climate change adaptation planning. These and other appropriate…….

As part of the adjustment to changing conditions, stakeholders may also wish to consider whether opportunities exist for targeting presently unexploited species, in a sustainable manner. Evidently, acceptance of ‘new’ or ‘non-traditional’ species will be affected by factors such as consumer perception, culture and taste, but such impediments may be overcome with the implementation of aggressive, innovative marketing programmes, education and outreach. The harvesting of non-exploited species, if found to be feasible, would not only diversify the options available to fishers for maintaining their livelihood, but might simultaneously alleviate the pressure on heavily exploited stocks. This would also make a positive contribution to the building of resilience into the sector. Agencies such as the Caribbean Regional Fisheries Mechanism (CRFM) and the OECS Fisheries Unit, whose missions already embody notions of adaptation, diversification and resilience building (though not explicitly defined in these terms), can play lead roles in such initiatives, in collaboration with other key stakeholders.

Since it is likely that climate change will impact negatively on the future availability of stocks, an overriding direct concern for fishers is the extent to which alternative forms of employment (seasonal or otherwise) can be pursued as an adaptation option. The pursuit of alternatives would help to compensate for expected reductions in revenues and livelihood support caused by climate change. However, it would require the intervention and assistance of Government and the Private sector, working in close collaboration with the fishing community and affiliates. In this regard, organizations such as fisheries cooperatives could play a significant role in assisting with the creation and sourcing of opportunities, as well as the 'retooling' of fishers with new skills.

Notwithstanding the above, the reality is that although local adaptation strategies will help to 'cushion' some present and future effects of climate change, global anthropogenic greenhouse gas emissions must be abated and stabilized urgently. There is a positive correlation between greenhouse gas forcing of the atmosphere and the severity of the impacts. The efficacy of adaptation also diminishes as the severity of impacts increase (IPCC 2001, 2007, Nurse and Moore 2007). It is therefore regrettable that stakeholders in the fisheries sector have not engaged in the global debate with the same vigour as interest groups in other sectors. Since the adverse effects of climate change are expected to be greatest on low-lying small islands (Nurse and Sem 2001, Mimura *et al*. 2007), the fisheries constituency must invest in its own self-interest and join the global lobby to for steep emission reductions and swift implementation of agreed protocols.

The international community is currently negotiating successor arrangements to the Kyoto Protocol, with a view to reaching agreement at the 15th Conference of the Parties (CoP) to the United Nations Framework Convention on Climate Change, scheduled for Copenhagen in 2009. Fisheries stakeholders should immediately seize the opportunity to have an effective voice at the remaining preparatory meetings and at the final decision-making forum. At the same time, the Caribbean fisheries sector must seek to equip itself to access the various climate change adaptation facilities that currently exists. The climate change Adaptation fund, established under the Kyoto Protocol, should be a prime target. The Fund was created specifically to assist vulnerable countries and communities adapt to the adverse effects of climate change, provided that certain conditions of eligibility are met.

Ongoing, focused research should also constitute a vital component of the adaptation package. While it is possible to learn and apply the lessons from observations and research conducted elsewhere, more effective adaptation programmes can be designed if there is robust, region-specific information available. In this context, key research questions such as the sample listed below, readily come to mind:

i) How will changing temperature, wind, salinity, and circulation regimes affect the spatial and temporal abundance and migration patterns of commercially important species?
ii) What is the level of understanding of the population dynamics and seasonal availability of non-exploited species? What is the *harvesting threshold* beyond which these stocks might crash
iii) Will there be a market for 'new' or non-traditional species? And what would be required to ensure the sustainability of that market?
iv) How do predators and prey respond under different climate change scenarios? (i.e. what is their sensitivity to *various increments* of warming, acidification, sea-level rise, etc)? What is their 'natural' adaptive capacity?
v) Will climate change alter the values of parameters commonly applied in fisheries management models to estimate optimal production, yield, and levels of stock?
vi) Will there be a need to modify existing fisheries regulations and practices (e.g. extend/reduce closed seasons; issuance of permits for various fisheries), and introduce new technologies?

Full or even partial answers to these and other questions would provide valuable guidance on key issues including the optimization of catch effort, the relative vulnerability of various fisheries, the structuring of bilateral and other fishing agreements with neighbouring states, and types of behavioural changes that stakeholders may be required to effect in the interest of minimizing livelihood dislocation as a result of climate change. Such information could also be used effectively for purposes of stakeholder training and awareness.

CONCLUSION

The observations presented above should provide a compelling reason for stakeholders in the Caribbean to accelerate the process of '*mainstreaming*' climate change considerations into ongoing fisheries management programmes. While climate change may be regarded simply as an '*additional stressor*, the difference is that it is one which the most vulnerable countries and communities have not invited upon themselves, and which they are poorly equipped to solve. Global and regional climate change assessments indicate that some of the Caribbean's most important economic and social sectors, including fisheries, are already being adversely impacted by climate change. Based on the current trend of increasing global greenhouse gas emissions and robust climate model projections, practically all sectors are likely to be severely affected in the future.

The solution to the climate change challenge is a global one, and the basis of that solution will emanate largely from outside the fisheries constituency. The framework for an international response is mainly being pursued under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol.

Yet, industry stakeholders in the Caribbean need to become more actively engaged in the global and regional debate, which hopefully will provide the consensus for a solution that is lasting and equitable. Only then are the legitimate concerns of the fisheries constituency likely to be fully ventilated, and access to available adaptation funding and other resources maximized. Such action must be regarded as a priority, if the Caribbean fisheries sector is to properly equip itself to adapt to the adverse consequences of a changing climate, with which it will be confronted for the foreseeable future.

LITERATURE CITED

Arcos, D.F., K.L. Cubillos and S.P. Nuñez. 2001. The jack mackerel fishery and El Niño 1997-98 effects on Chile. *Progress in Oceanography* **49**:597-617.

Bakun, A. 1990. *Science* **247**:198–201.

Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* **436**(7051):686-688.

Barry, J., C. Baxter, R. Sagarin, and S. Gilman. 1995. Climate-Related, Long-Term Faunal Changes in a California Rocky Intertidal Community. *Science* **267**(5198):672 - 675.

Diffenbaugh, N., M. Snyder, and L. Sloan. 2004. Could CO_2-induced land-cover feedbacks alter near-shore upwelling regimes? *Proceedings of the National Academy of Science* **101**:27-32.

Edwards, M. and A. Richardson. 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature* **430**:881-884.

Emanuel, K. 2006. Increasing Destructiveness of Tropical Cyclones Over the Past 30 Years. *Nature* **436**:686-688.

Escribano, R. and W. Schneider. 2007. The structure and functioning of the coastal upwelling system off central/southern Chile. *Progress in Oceanography* **75**(3):343-347.

Fabry**,** V.B. Seibel, R. Feely and J. Orr, 2008. Impacts of Ocean **A**cidification on Marine Fauna and Ecosystem Processes. *ICES Journal of Marine Science* **65**:414–432.

FAO. 2005. I*ncreasing the Contribution of Ssmall-scale Fisheries to Poverty Alleviation and Food Security*. FAO Technical Guidelines for Responsible Fisheries Number 10. Rome, Italy. 79 pp.

Field, D., T. Baumgartner, C. Charles, V. Ferreira-Bartrina and M. Ohman. 2006 Planktonic Foraminifera of the California Current Reflect 20th-Century Warming. *Science* **311**(5757):63-66.

Fields, P.A., J.B. Graham, R.H. Rosenblatt, and G.N. Somero. 1993. Effects of expected global climate change on marine faunas. *Trends in Evolution and Ecology* **8**:361-367.

Garpe, K., S. Yahya, U. Lindhal and M. Ohman, 2006. Long-term effects of the 1998 coral bleaching event on reef fish assemblages. *Marine Ecology Progress Series* **315.**

Glynn, P.W. 1984. Widespread Coral Mortality and the 1982/83 El Nino Warming Event. *Environmental Conservation* **11**:133-146.

Goreau, T., T. McClanahan, R. Hayes, and A. Strong. 2000. Conservation of Coral Reefs after the 1998 Global Bleaching Event. *Conservation Biology* **14**:5-15.

Harley, C., A. Hughes, K. Hultgren, B. Miner, C. Sorte, C. Thornber, L. Rodriguez, L. Tomanek, and S. Williams. 2008. The Impacts of Climate Change in Coastal Marine Systems. *Ecology Letters* **9** (2):228-241.

Hayes, R.L. and T.J. Goreau. 2008. Satellite-derived sea surface temperature from Caribbean and Atlantic coral reef sites, 1984-2003. *Reviews in Tropical Biology* **56**(1):97-118.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research* **50**:839-866.

IPCC. 1990/ *First Assessment Report: Impacts Assessment of Climate Change – Report of Working Group II*. Pages 8.21-6.28 in: W.J. McG. Tegart, W.J. McG., W.Sheldon, and D.C.Griffiths (Eds.). Australian Government Publishing Service, Canberra, Australia.

IPCC. 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. J.T. Houghton,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskelland, C.A. Johnson (Eds.). Cambridge University Press, Cambridge, U.K. 881 pp.

IPCC. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M. Tignor, H. Miller and Z. Chen (Eds.). Cambridge University Press, Cambridge, U.K. 996 pp.

Kleypas, J., R. Feely, V. Fabry, C. Langdon, C. Sabine, and L. Robins. 2006. Impacts of ocean acidification on coral reefs and other marine calcifiers: a guide for future research. Workshop Report, NOAA, USGS and NSF, 89 pp.

Krishna, K.M. 2008. Coastal upwelling along the southwest coast of India – ENSO modulation. *Ocean Science Discussion* **5**:123-134.

Lal, M., H. Harasawa, and K. Takahashi. 2002. Future Climate Change and its Impacts over Small Island States. *Climate Research* **19**:179-192.

Lehodey, P., F. Chai, and J. Hampton. 2003. Modeling the Climate-related Fluctuations of Tuna Populations from a Coupled Ocean-Biogeochemical Population Dynamics Model. *Fisheries Oceanogra*phy **13**:483-494.

McConney, P., R. Pomeroy, and R. Mahon. 2003. *Guidelines for Coastal Resource Co-Management in the Caribbean: Communicating the Concepts and Conditions that Favour Success*. Caribbean Conservation Association, Barbados. 56 pp.

McGregor, H., M. Dima, H. Fischer, and S. Mulitza. 2007. Rapid 20th century increase in coastal upwelling off northwest Africa. *Science* **315**{5812}:637-639.

McWilliams, J.P., I.M.Cote, J.A. Gill, W.J. Sutherland, and A.R. Watkinson. 2005. Accelerating impacts of temperature-induced coral bleaching in the Caribbean. *Ecology* **86**:2055-2060.

Mimura, N., L. Nurse, R. McLean, J. Agard, L. Briguglio, P. Lefale, R. Payet, and G. Sem. 2007. *Small islands*. Pages 684-716 in: Chapter 16, IPCC Fourth Assessment Report, Working Group II, Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambride, UK. 684-716.

MOHA(Ministry of Home Affairs, Maldives). 2001. *First National Communication of the Republic of Maldives to the United Nations Framework Convention on Climate Change*. Ministry of Home Affairs, Housing and Environment, Malé, Republic of Maldives, 134 pp.

Murawski, S. 1993. Climate Change and Marine Fish Distributions: Forecasting from Historical Analogy. *Transactions of the American Fisheries Society* **122**:647–658.

Nurse, L. and G. Sem. 2001. Small Island States. Pages 843-875 in: J.J. McCarthy, O.S. Canziani, N.A. Leary, D J. Dokken. and K.S. White (Eds.) *Climate Change 2001: Impacts, Adaptation and Vulnerability – Contribution of Working Group II to the Third Assessment Report*, Cambridge University Press, Cambridge, UK.

Nurse, L. and R. Moore. 2007. Critical considerations for future action during the second commitment period: A small islands perspective. *Natural Resources Forum* **31**:102-110.

Oxenford, H, R. Roach, A. Brathwaite, L. Nurse, R. Goodridge, F. Hinds, K. Baldwin, and C. Finney. 2008. Quantitative observations of a major coral bleaching event in Barbados, Southeastern Caribbean. *Climatic Change* **87**:435-449.

Perry, A., P. Low, J. Ellis, and J. Reynolds. 2005. Climate change and distribution shifts in marine fishes. *Science* **308**(5730):1912-1915.

Pomeroy, R.S and F. Berkes. 1997. Two to tango: The role of government in fisheries co-management . *Marine Policy* **21**:465-480.

Richardson, A. and D. Schoeman. 2004. Climate Impact on Plankton Ecosystems in the Northeast Atlantic. *Science* **305**(5090):1609-1612.

Roemmich, D. and J. McGowan. 1995. Climatic Warming and the Decline of Zooplankton in the California Current. *Science* **267**:(5202):1324-1326.

Sagarin, R.D., J.P. Barry, S.E. Gilman, and C.H. Baxter. 1999.. Climate-related changes in an intertidal community over short and long time scales. *Ecological Monographs* **69**:465-490.

Salas S., R. Chuenpagdee, J. Seijo, and A. Charles. 2007. Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean. *Fisheries Research* **87**:(1):5-16.

Schumann, E.H. 1999. Wind-driven mixed layer and coastal upwelling off the south cost of South Africa. *Journal of Marine Research* **57** (4):671-691.

Wiafe, G., H. Yaqub, M. Mensah and C. Frid. 2008. Impact of climate change on long-term zooplankton biomass in the upwelling region of the Gulf of Guinea. *ICES Journal of Marine Science* **65**:318–324.

Walther, G-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. Beebee, J-M. Fromentin, O. Hoegh-Guldberg and F. Bairlein. 2002. Ecological responses to recent climate change. *Nature* **416**:389-395.

Wilkinson, C.R. (Ed.). 2000. *Status of Coral Reefs of the World 2000*. Australian Institute of Marine Science, Townsville, Australia. 363 pp.

Winder, M., and D. Schindler. 2004. Climate change uncouples trophic interactions in an aquatic ecosystem. *Ecology* **85**:(8):2100-2106.