Methodology to conduct rapid ecological assessments of the impact of hurricane damage to forests and watersheds

Jan Meerman & Oswaldo Sabido,

2016

BELIZE • FOREST • DEPARTMENT •

Index

A. INTRODUCTION

Hurricanes are a common meteorological event for Belize which is situated in the south west quadrant of the north Atlantic hurricane basin. It is estimated that in the past 60,000 years about 10,000 hurricanes have affected Belize and more recent historical records show that in the past 165 years Belize has been affected by 24 hurricanes or 1 every 6 years or so. 1

Figure 1. Cumulative path of hurricanes

Ecological evidence clearly demonstrates that our forest ecosystems have adapted to frequent severe wind disturbances and have developed mechanisms for efficient recovery. This degree of adaptation is perhaps best demonstrated in species like Mahogany, one of the most important economic timber species in Belize which depends on large scale disturbances of the forest canopy to regenerate adequately at the forest wide level.

The Belizean forest and other similar forest in the north Atlantic hurricane basin have developed and maintained the ecological resilience necessary for recovery from natural catastrophic events such as hurricanes. However the advent of historically recent human intervention in the forest at increasingly larger scales initially for timber extraction and subsequently for agricultural and other development has impacted those ecological processes in our forests that have been developed through millennia of severe wind disturbance which allow for the forest to recover relatively quickly after a hurricane.

Our relative recent awareness of climate change and the impacts on our forest ecosystems have increased our awareness of the higher probabilities of more frequent and mores severe hurricanes affecting the north Atlantic hurricane basin. Paradoxically at a time when our forest are experiencing some of the highest levels of human impact since the decline of the ancient Mayan civilization, our awareness of the goods and services which forests provide for our very existence is slowly increasing. Within the context of climate change and its impacts on our Belizean society, our forests are crucially important for maintaining our own resiliency as a country to its negative impacts. Our forests play a crucial role in ameliorating the effects of climate change. At the same time they are also subject to the adverse impacts of climate

[1] Cho,P. and Sabido,O. A Strategy to Guide the Response of Hurricane Damage to Belize's Forests, CATIE & Belize Forest Department, Belmopan, 2011

change at a time when their natural resiliency is increasingly threatened by human activities such as deforestation, indiscriminate use of fires, and unsustainable logging practices. Post hurricane activities such as improperly executed salvage logging and the indiscriminate use of fire in hurricane affected areas additionally contribute to a decrease in forest resiliency and further exacerbate the effects of hurricanes on forest services such as watershed protection.

In the early 1990's and primarily as part of a global preoccupation with efforts to sustainably manage tropical forests, a series of initiatives were undertaken in Belize to promote and implement sustainable forest management principles in the management of forest reserves. Subsequently in efforts to comply with CITES requirements for the export of Mahogany and to meet eligibility for Forest Stewardship Council certification, sustainable forest management was also introduced to private forest land. However recent experiences in the management of hurricane impacted forest after Hurricane Richard have highlighted the need to ensure that in spite of severe natural forest ecosystem disturbances, the objectives of sustained forest management plans and long term forest licenses are not compromised or abandoned by what is perceived to be an imperative to carry out hurricane salvage operations under an unfortunate belief that no further damage can be perpetuated against the forest functions that provide the goods and services which we are dependent on.

In recent years, the experience with addressing the issues and concerns arising from hurricane impact on forests in a forest management planning scenario can perhaps be encapsulated by the following:

- Hurricane impacts are often made more severe by a lack of forward planning.
- Salvage guidelines are inadequate and lack monitoring.
- There is a lack of effective preparation for post hurricane fire management.
- Forest managers lack capacity to carry out a systematic and standardized hurricane impact assessment on the forest.
- Planning is carried out after the hurricane when conditions for planning are not optimal.
- Goals and objectives of forest management plans are overlooked during post hurricane operations.
- The protection of Forest functions is not prioritized.
- Community benefits from post hurricane operations tend to be overlooked.
- Coordination between GOB institutions, NGO's, and industry is weak.

In 2011 with the support of CATIE, Dr. Percival Cho developed a series of technical recommendations in a document entitled A Strategy to Guide the Response to Hurricane Damage to Belize's Forests based on scientific knowledge on hurricane impacts on forests

including his own research which also looks at the experiences and lessons learnt from Hurricane Iris in 2001 and Hurricane Hattie in 1961. The hurricane response strategy highlights the following:

- Provide guidelines for rapid assessment and valuation of forest damage;
- Provide stipulations for the use of forest trees felled by the hurricane;
- Promote strategies for the prevention and protection of damaged forests from further degradation, such as through fire, so that regenerative processes are not undermined;
- Provide for the systematization and dissemination of experiences of hurricane response; (For post-hurricane forest management, knowledge about the composition and structure of survivor trees is crucial, especially if salvage logging is contemplated.)
- Highlight potential areas to be addressed by regulations and administrative provisions necessary to ensure compliance with the provisions of the strategy, restrict activities so as not to promote land use change, and encourage reforestation.

In 2014 the Ministry of Forestry, Fisheries and Sustainable Development (MFFSD), the European Union (EU), and the United Nations Development Programme (UNDP) agreed to support a project entitled "Enhancing Belize's Resilience to adapt to the effect of climate change" with a component specifically focused on forest management entitled "Building capacities for the restoration of watersheds impacted by natural disasters". This component is managed by the Forest Department. The project will provide capacity in the form of training, equipment and methodological resources to stakeholders involved in the management of forests subject to recent hurricane disturbances, including Hurricane Richard in 2010, Hurricane Dean in 2007 and Hurricane Iris in 2001.

This particular consultancy which arises from this project is concerned with the development of a practical and concise methodology for the conduct of on-ground rapid ecological assessments (REAs) in forested areas damaged by hurricanes, with the main focus being on:

i. Assessing the extent of damages to the forest vegetation including riparian zones based on relevant indicators;

ii. Using the results of (i) to determine the expected impact on animal, bird, insect and aqua-fauna populations;

iii. Using the results of (i) and (ii) to determine the impact on the regenerative capacity of the forest;

iv. Using the results of (iii) to assess the potential ecological impacts of salvage logging.

The methodology must be easily implemented by field staff with little or no ecological training, must be entirely field-based, and require little or no post-field work report writing. It must be accompanied by one comprehensive form which allow data collection, synthesis and results reporting.

As can be appreciated from the objectives of the consultancy, this document seeks to address primarily the first strategic recommendation contained in the response to hurricane damage but also includes elements which partially address the other strategies. Many of the methodologies used in this study are methodologies recommended in the Strategy to Guide the Response to Hurricane Damage to Belize's Forests, even though sometimes with limited modifications.

B. CONSULTANCY PROCESS

B.1 Selection of stakeholders

The stakeholders were selected by the Forest Department, and consisted principally of all the long term and medium term licensees with their contact information. During the consultancy the consultants realized that many protected areas are essentially managed forests and as such, the Protected Area Managers (NGO's) were included as stakeholders.

The list of stakeholders invited is included in Appendix 1

B.2 Literature review

Although there are many studies on the impacts of hurricanes on forests many of these studies to a large extent concentrate on hurricane damage in the more temperate zones of the north Atlantic hurricane basin. However there are a few reports on hurricane impact in the neo-tropical forests from studies carried out in Puerto Rico, Nicaragua, and from Belize.

Dr. Cho very generously shared copies of literature on hurricane impacts on forests in his possession including his PhD thesis. Our own literature search turned up studies carried out mostly in the south-east USA. A list of the literature consulted is provided in Appendix 3.

B.3 Interviews

Interviews were carried out primarily with the more accessible forest licensees engaged in sustainable forest management and having had recent experience with responses to hurricane damage to the forest under their management. It included licensees engaged in the management of both broadleaf and pine forest. The interviews were carried and designed to elicit first-hand information and perceptions from forest managers with regards to their prioritization of responses to hurricane damage to their forests, their technical and institutional capacity to respond and degree of planning if any already in place, their capacity needs, and any general concerns or issues. These initial interviews also allowed for a modification of the structure of the questionnaires that were sent out to all the stakeholders in order to facilitate the responses.

B.4 Questionnaires

A standard questionnaire was developed and sent to the stakeholders in electronic format for their completion. Two categories of forest managers are distinguished: the long term

forest licensee whose primary interest is forest management for timber production and the forest manager whose primary interest is forest management for biodiversity conservation, the latter category encompassing most of the NGO forest managers.

The following section summarizes the responses received from the questionnaires that were sent out (with the original question in Bold):

Number of staff: Varied from 3 to 72 depending on the type of organization, the size of the organization, and the level of value added to the timber product.

Number of field staff (staff that can be mobilized for assessment(s): This varied from 3 to 72 but on average was less than for total staff. It was pointed out that the field staff would be the personnel that would be expected to implement damage assessment protocols.

Do you have a stock survey of the total licence area and if so, to what degree? This varied according to forest management category where areas managed for biodiversity conservation did not have a stock survey but in one case had a carbon stock survey (Golden Stream) while most forest managers engaged in sustained timber production had stock surveys for the areas that had been logged under their long term forest license. Pre-harvest inventory in the pine forests was based on sampling rather than 100% inventory of commercial species being harvested.

In the case of hurricane damage to the licence area what would be your principal focus?: The majority of responses listed salvage operations with some clarifications. Salvage was also included in responses for areas being managed for non-timber purposes. In one instance salvage operations was identified for the production forest and while in others the rationale for salvaging was to reduce fuel loads. It was recognized that salvage operations are expensive. Other responses included fire management through fire prevention, detection, and prescribed burning because of the high risk of wildfires and the need to protect natural regeneration. Another response was to clear the areas used for tourism and environmental education activities.

How would you coordinate with the FD?: The sentiment that the license holder should be in charge was predominant. Others saw the salvage permit as the means of coordination. Another response saw the Southern Fire Working Group as the mechanism for coordination since the FD is also a member of the working group. Another response suggested the Protected Areas management unit and the local range office but at the same time opined that they may be busy otherwise in other hurricane response activities. One response pointed to the need for FD assistance in the case of a wildfire.

If salvage is your main focus, would you go for just the valuable species or do a general salvage?: The responses varied from salvage of Mahogany only as the salvage of the secondary species would slow the salvage process to the scenario where if subcontractors

are being used they would salvage all the commercial timber since they are being paid by volume. However the general responses seem to indicate that all the commercial species that are readily marketable would be salvaged.

In the case of hurricane damage to the licence area what would be your first steps?: An over flight of the hurricane affected area to assess damage was in most cases the first response followed by opening up access over the property or to important features of a protected area. The use of remote sensing was also mentioned in some responses. Wildfire prevention was also identified as a first step.

What would be your material/equipment/staff needs for such a first step and would you have those available?: The hiring of a plane to carry out the over flight was identified as a need to implement the first step although one licensee responded that he had his own. The availability of heavy equipment to create access to hurricane damaged forest may be limited and therefore outsourcing may be required. Outsourcing of some small equipment such as chainsaws and other manual tools would be needed for one forest manager. Portable mills may need to be outsourced. Basic equipment seems to be available for some. Outsourcing of expertise to assist with carrying out damage assessment may be required. Some wildfire fighting equipment may not be available in country.

What would be the subsequent steps and what would be their timing? Opening up of access roads with limitations in the use of heavy equipment to the drier months as well as negative impacts such as erosion were cited. Milling trials to establish the quality of the salvage timber was also mentioned. Site survey, evaluation, and salvage over subsequent years were also mentioned as well as the effects of the lunar cycle on the quality of the wind damaged timber. Criteria to determine whether forest restoration activities and recreation activities need to be modified were also pointed out as a requirement. Fire prevention and pre-suppression planning before the start of the dry season was identified as a subsequent step. Funding for implementation was also mentioned. Assessment of damage and categorization into damage classes in order to prioritize areas for salvage logging starting with the highest damage classes at least one month after the storm was mentioned.

How do you consider post-hurricane wildfire risk, and what would you do?: Post – hurricane wildfire risk was considered as high. Wildfire risk originating from agricultural fires outside of the forest management area was considered to be high and fire prevention planning and activities including emphasis on raising public awareness were identified. Early detection and suppression including the use of heavy earth moving machinery also came up in the responses as well as the need for training in fire management.

Based on all these combined post-hurricane actions that you expect that you would need to undertake, what are your material/equipment/staff/training needs?

- Fire suppression including back firing techniques in pine
- Fire suppression skills for tractor drivers
- S160 training for 6 community fire prevention officers
- Community fire management training
- Use of GPS
- Assessing hurricane damage
- Seed tree recognition and other residual trees that should not be felled
- Salvage assessment skills
- Species recognition skills
- Aerial spotting and assessment techniques

Personnel (expert) needs:

- Someone with on the ground experience is need to guide trained staff
- More trained staff for large fires

Equipment needs:

- Updating of old equipment
- Fuel for heavy duty equipment for fire suppression
- Rations for staff on the fire
- Basic hand line tools for buffer communities milpa fire management (council rakes, bladder bags, swatters, personal protective equipment, etc.)

B.5 Workshops

Three workshops were held with stakeholders according to region commencing with the first one in Belize City for the convenience of those forest managers from the north and/or with Belize City based offices. The second workshop was held in Punta Gorda for the southern based stakeholders and the third workshop was held in San Ignacio for those from the west including the FD. Attendance at the workshops was very good with most if not all invited forest managers having representation at the workshops. A copy of the document "A Strategy to Guide the Response to Hurricane Damage to Belize's Forests" was made available to all the participants from the industry and NGO sector. The purpose of the workshops was as follows:

- To introduce stakeholders to the background and goals of the project
- To present to stakeholders the results of the interviews/questionnaires for their discussion including sharing of experiences and validation.

- To present to the stakeholders an outline of the methodology that we proposed for discussion, recommendations, and their support as future users of the methodology.

B.6 Study of existing hurricane damage images

Using images taken by the lead consultant, it was tested whether damage categories could be reliably identified using aerial photography. Some of these images and their interpretation can be found in Appendix 2.

B.7 Conclusions from the process

The consultation process indicates that most forest managers have an appreciation of both the economic and ecological impact of hurricanes on our forests and specifically for those who have experienced hurricane impacts on their specific forest management unit.

There seems to be a willingness to incorporate in their individual forest management tool box the methodology and techniques that are best suited to address hurricane impacts on their forest management areas albeit these methodologies and techniques unlike other forest management techniques such as stock surveys will not be practiced and improved on a continual basis since these are events that fortunately occur only periodically.

None of the stakeholders had any sufficient base line data on existing animal, bird, insect and aqua-fauna populations for their management area. Stakeholders realized that implementing base line data gathering programs followed by continuous monitoring would be very time consuming and expensive. Meanwhile they questioned the value of such an effort for the establishment of the regenerative capacity of the forest. Instead they more valued a clear protocol of steps to be taken in the case of a hurricane incidence. Overall, hurricanes have hit us while we were unprepared and our actions tended to be based on ad-hoc decisions and not always very effective.

What the stakeholders have asked is for clear and consistent policy guidelines developed in consultation with them and which are translated into methodologies for best management practices in hurricane affected forest areas which they can implement with the support of the FD.

Understandably there are beliefs and perceptions about the management of hurricane affected forests that are not necessarily founded on scientific evidence and these need to be clarified and put into proper perspective by promoting consistent and technically sound guidelines.

As for all management activities, there is a need to establish effective monitoring mechanism which over time can serve as indicators of whether methodologies are effective and also allow for the process of adaptive management to be maintained.

The fire fighting experiences of the Southern Belize Fire Working Group (often dubbed Southern Belize Fire Working Alliance) was seen as worthwhile and it should be investigated whether this concept can be repeated in each district/region of Belize.

A variant of this could be that the Forest Department develops its own Hurricane Response plan which includes a multidisciplinary team including other stakeholders to be activated when hurricane is imminent or immediately after.

The Forest Department needs to have clear policy with regards to wildfire management in post hurricane license areas.

Experience in Yalbac has shown that fire suppression methodology used in savannah and pine forests are not the most effective in broadleaved forest. Training in effective fire suppression techniques for broadleaved forest needs to be introduced and developed.

Generally, the stakeholders have indicated that dealing with post-hurricane situations, and especially post-hurricane fire situations present a severe drain on their resources. In the case of a hurricane incident, a role of the Forest Department could be to leverage assistance not just to the Forest Departments itself, but also for the other stakeholders.

Analysis of aerial imagery of past hurricane damage (Iris 2001 and Richard 2010) showed that it was possible to assign broad damage classes using such images. However, it was found that it was impossible to distinguish reliably between “damage to branches” and mere defoliation. See Appendix 2 for details.

C. METHODOLOGY TO CONDUCT A RAPID ECOLOGICAL ASSESSMENT

C.1 Pre-hurricane activities

This phase is the normal period between hurricanes. We don't know when the next hurricane will strike, it may be next year, it may be 20 years from now, but we just want to be prepared and get our act together.

C.2 Data gathering

The particular assignment for this study was to development of a practical and concise methodology that will facilitate "on-ground" rapid ecological assessments (REAs) in forested areas damaged by hurricanes. The focus being on:

1) Assessing the extent of damages to the forest vegetation including riparian zones based on relevant indicators;
2) Using the results of (1) to determine the expected impact on animal, bird, insect and aqua-fauna populations;
3) Using the results of (1) and (2) to determine the impact on the regenerative capacity of the forest;
4) Using the results of (3) to assess the potential ecological impacts of salvage logging.

However, based on the stakeholder feedback the following became clear.

- There is little or no information on forest composition at the tree level. Licence holders have a rough idea based on commercial species, but the level of detail is very coarse (2% inventory), the most detailed information is available from actual logging blocks for which an APO was prepared. There is no incentive for inventories in the conservation zones within forest licence areas. Managers of conservation forests are even worse of; with information usually at the ecosystem level.
- There is hardly any baseline information available on mammals, birds, insects and aqua-fauna. In some forests, there is some research going on into some groups of wildlife, usually Jaguars. In Belize we are a long way away from any level of mammal, bird, insect and aqua-fauna monitoring. The monitoring working group led by ERI from the University of Belize has until now, not been able to design monitoring protocols for virtually all groups of organisms.
- Establishing baseline data for the flora and fauna groups is tremendously expensive and time consuming. There is no incentive for either the licence holders or the conservation managers to venture into this field

- Impacts of salvage logging have not been studied in Belize. However, identification of areas for salvage depends largely on access and on the identification of sensitive areas in the Long Term Forest Management Plan. Any conservation areas identified in this FMP should remain conservation areas in any salvage operation.

Effectively there are two, divergent, objectives amongst the stakeholders:

- Salvage logging (for licence holders)
- Recovery of biodiversity and ecological services (for conservation forest managers).

One common theme appeared that has the attention of both types of stakeholders: prevention of wildfires

C.2.1 Data gathering guidelines for licence holders.

Continue gathering any base line data that you are already gathering, maybe as part of your stock inventories and or permanent sampling plots if any have been established.

Encourage research by third parties inside the licence area.

Make sure that this information is available not just as hardcopy but also in electronic format. Electronic format includes PDF files of documents and GIS files (shape files).

Deposit copies of all electronic files in a centralized database. In the absence of this in Belize, copies should at least be shared with the Forest Department and with the Environmental Resource Institute of the University of Belize. Companies that have websites could store reports and data on-line. Make sure that no sensitive or proprietary data is shared on-line.

C.2.2 Data gathering guidelines for Protected Area managers

Continue gathering any base line data that you are already gathering, maybe as part of permanent sampling plots if any have been established.

Map ecosystems within the protected area that you are managing. This may already be available as part of a management plan for example. The ecosystems map should be based on the Belize Ecosystems Map that is made available through online platforms such as http://www.biodiversity.bz/ or the BNSDI: http://geoserver.bnsdi.gov.bz Updates of this map are being made available every couple of years, but as this is a map on a national scale a refinement for your protected area may be appropriate. The resulting ecosystem map can serve as a proxy for biodiversity values and environmental services values.

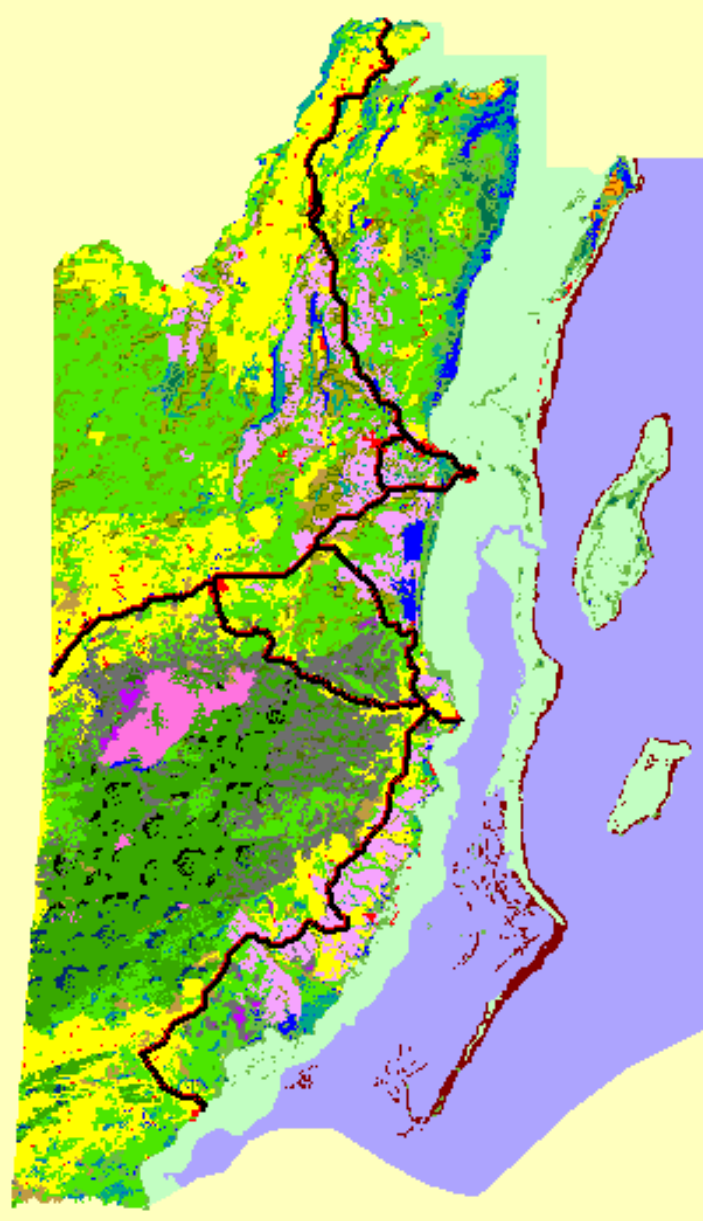


Figure 2. Belize Ecosystems Map in GIS format that can be downloaded from online resources

Encourage research by third parties inside the protected area.

Make sure that all pertinent information is available not just as hardcopy but also in electronic format. Electronic format includes PDF files of documents and GIS files (shape files).

Deposit copies of all electronic files in a centralized database. In the absence of this in Belize, copies should at least be shared with the Forest Department and with the Environmental Resource Institute of the University of Belize. Companies that have websites could store reports and data on-line. Make sure that no sensitive or proprietary data is shared on-line.

C.2.3 Equipment, hardware, software

Make sure you ALWAYS have available the following equipment in good working order.

- Cameras with integrated GPS
- Stand-alone GPS
- Chainsaws
- Machetes and files
- Compasses
- Rite in the rain paper/note books, pencils
- Clipboards
- Batteries/chargers for equipment

Additional equipment specifically for licence holders:

- Diameter tapes
- Tree callipers
- Clinometers or laser range finders

Software needs include

- ArcGIS or similar software, including someone that is trained in using it. In the absence of this software and/or capacity identify a consultant that is capable of taking on such a task.
- Ecosystems maps from from online resources such as as http://www.biodiversity.bz/ or the BNSDI: http://geoserver.bnsdi.gov.bz .
- Digital elevation models from http://www.jspacesystems.or.jp/ersdac/GDEM/E/4.html or anything more accurate (LiDAR if and where available).
- Software to link GPS with digital pictures: http://www.geosetter.de/en/, https://code.google.com/p/gpicsync/.
- Google Earth is increasingly a source of high detail and up to date imagery, even of forested areas.

Heavy equipment

- Maintain heavy Equipment for clearing of roads etc. or source a provider in the event of an emergency

C.2.4 Monitoring of neighbouring areas, boundaries

Always keep a tab on what is happening on your boundaries, with particular attention to milpa clearings and other deforestation activities. This monitoring can take place from any angle, from the road, from the air and from satellite imagery.

Lighthawk http://www.lighthawk.org/ can be a low cost partner in this type of monitoring.

C.2.5 Training

Consider the following training needs.

- Fire fighting
- First Aid
- (Tree) species recognition
- GPS and compass reading
- GIS and other software training

Remember that your staff will change over time and that training will have to be repeated, sometimes every year.

C.3 Activities when under imminent Hurricane threat

When a hurricane threatens, the normal hurricane preparedness actions need to be carried out. Prepare for the worst and human safety comes first. Remember that the actual path of the hurricane is ALWAYS unpredictable.

C.4 Post-hurricane immediate actions - first phase

This phase comes into action as soon as a hurricane has passed and affected your management area.

C.4.1 Over flight options and methodologies

When it comes to taking stock of the damage the hurricane has done, one of the first actions to take will be an aerial reconnaissance. This aerial reconnaissance needs to be carried out at two levels:

C.4.2 National aerial reconnaissance

This will be an over flight carried out on a national scale. Forest Department can formulate an agreement with NEMO to take on the preliminary damage assessment of forested areas by piggy-backing on NEMO flights. NEMO recognizes three phases of damage assessment and the Forest Department would have to integrate these into its program:

- The Forest Department would have to ensure that a preliminary report be submitted within a 9 hour period describing the extent of the forest damage. This does not mean that subsequent flights should be launched to obtain more detailed information as per below, rather an effort should be made to collect all data on the first flight, where possible, and preliminary data analysis be performed to estimate the extent of damage.
- More detailed analysis of the data should produce estimates of the degree of damage (area of different damage classes) within 2 days of the initial flight. This phase may involve some ground sampling to compliment photogrammetry.
- More detailed analysis of flight and ground data should produce estimates of economic loss to the timber sector and costs in terms of environmental damage. This report should be prepared within 3 weeks of the initial flight. This phase will involve more intensive ground sampling/truthing.

While fixed wing planes generally provide acceptable results (based on consultant experiences), helicopters offer many advantages over fixed-wing aircrafts for this type of rapid assessment. Helicopters offer ease of manoeuvrability over forested, mountainous areas and can provide a better base from which to take aerial photography using the camera pod in the nose (if available) or the glass base in the cabin. Helicopters can also offer a more stable base from which to obtain flight altitude – an important parameter for determining scale of aerial photographs. In addition, the geo-referencing of an amateur aerial photograph is more accurate from an aircraft moving at moderate speed than from one moving in excess of 150 mph. The disadvantage is the higher cost of helicopters against fixed wing planes.

Geo-referencing of pictures has become more straightforward now that more and more cameras have a built in GPS. There also exists free software that makes it easy to link GPS tracking data (The GPS should have tracking activated) with the digital pictures taken during a flight: http://www.geosetter.de/en/ and https://code.google.com/p/gpicsync/. The principal requirement being that the time on the camera and of the GPS have been synchronized before the start of the flight.

In preparing for and carrying out aerial damage assessment the following should be considered:

The first phase of aerial assessment should be to determine the path of the hurricane as provided by the Hydromet Department. This data need not be specially requested from the Hydromet since the data is provided publicly on internet updates in the form of estimated latitude and longitude for the centre of all hurricanes which affect Belize (if the Belize weather radar is working, this will provide valuable data as well.

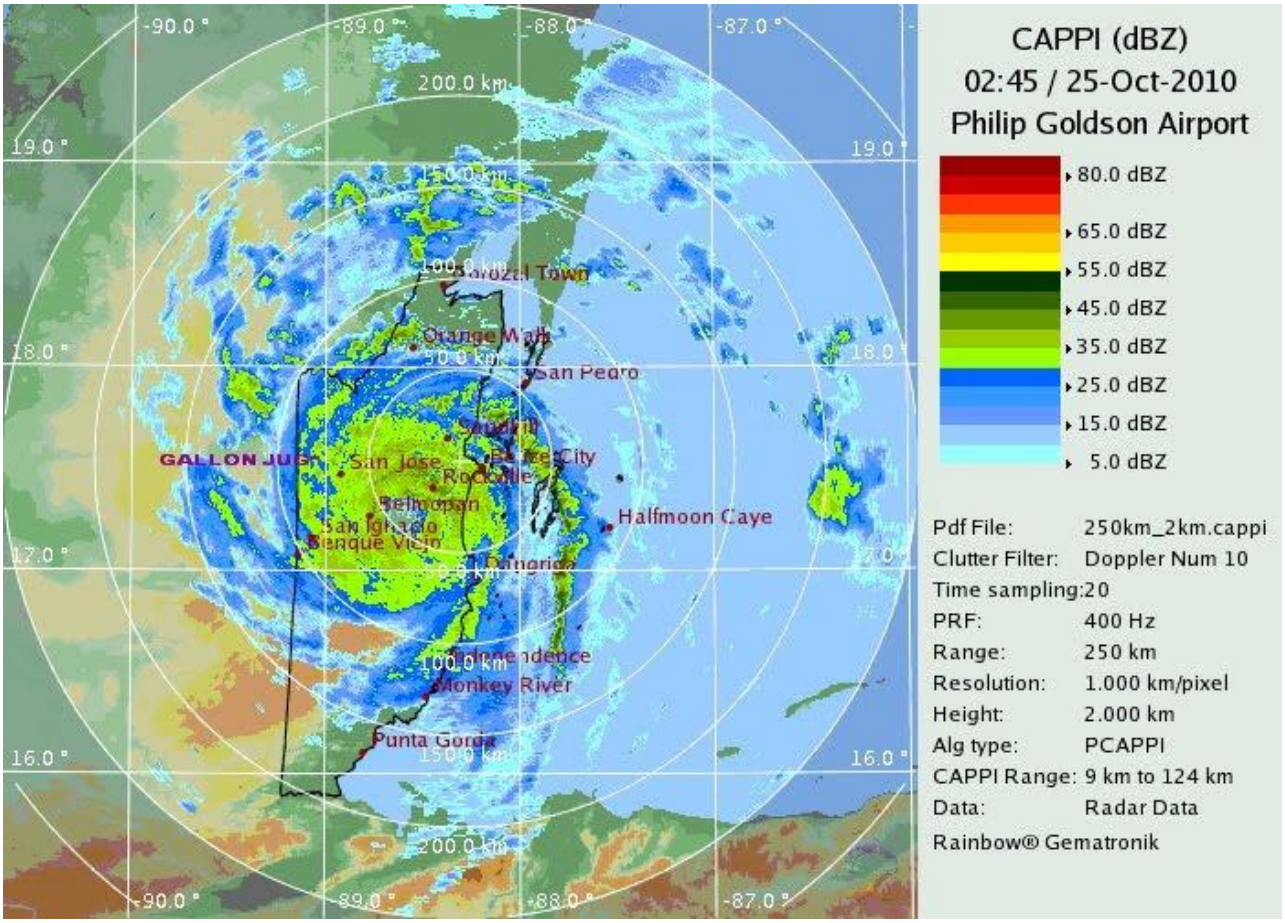


Figure 3. Belize Hydromet radar image of Hurricane Richard

As soon as possible after the all clear, and in reasonable weather (low hanging clouds are an issue), a flight should be launched which traces the centre path of the hurricane from the coast to the Guatemalan or Mexican border, while being recorded on GPS. In the 2011 Response Strategy, Cho and Sabido recommended a minimum of 10 aerial photographs should be taken from approximately nadir-viewing position spaced equally along the centre path in divisions of distance determined from pre-flight calculations (which would be close to 1 photograph per 10 km), the current view is that this is too limited. Essentially there is no maximum of pictures that need to be taken.

A good altitude for a flight is anywhere from 500 to 800 metres.

Once at the western border, the flight should maintain a northern bearing until it approaches the visible northern perimeter of damage, and then follow this perimeter eastward, al the will taking pictures.

Note that the heaviest damage will be on the northern section of the hurricane path. It will not be possible to estimate the actual damage based on the path of the hurricane. The northern edge of damage will have to be established by eye. The edge of the damage is typically quite visible, but note that the "edge" may not be straight.

Figure 4. Edge of Hurricane Damage after Hurricane Iris (Meerman)

Once at the coast, the flight should maintain a southerly bearing until it approaches the southern edge of the hurricane damage, from there the southern edge will need to be followed until the western border is again reached.

From this point on, additional west-east flights can be flown in order to "fill in" the area. The width of the path will vary from case to case.

Although it is advisable that this method be tested first, previous experience with aerial assessment of hurricane damage by the consultant provides indication that it will work.

C.4.3 Local aerial reconnaissance

Aerial reconnaissance for an individual licence area or protected area essentially follows the same protocol as the national aerial reconnaissance with the following important differences:

It won't be possible to piggyback on NEMO efforts; this is a flight that you will have to pay for yourself. Note that it may not be advisable to rely on free Lighthawk flights. They are in Belize only for some time of the year (typically end of dry season) and you can't wait that long.

The area to be flown will be smaller, but it should be remembered not to stick too tightly to the boundaries of the licence area/protected area. Flying the periphery can yield important data on what is happening just outside the borders of your area!

Depending on the size of the area, a helicopter flight may be more appropriate than a fixed wing over flight. We are now sampling a smaller area and we may want the detail that only a helicopter flight can offer.

C.4.4 Remote Sensing

Satellite data analysis should complement the aerial survey; however, the use of remote sensing for analysing forest damage caused by hurricanes has its limitations. Firstly, cloud free satellite imagery may not be available until many weeks or even months after the hurricane impact. Secondly, forest damage can be greatly over estimated from satellite data which uses NDVI or other band-ratio type indices to determine damage level. Defoliation can result in large changes in NDVI but does not relate to any meaningful interpretation of forest damage.

Alternatively, remote sensing can easily under-estimate damage. After Hurricane Richard in 2010, based on on-the-ground observations, the area of damage was much greater than identified from Satellite imagery by Cathalac immediately after the hurricane.

Thus, satellite based assessments must be carefully interpreted and should not be used as the sole means of assessment. The advantage is that hurricane damage typically remains identifiable do some degree on satellite imagery until at least two years after the actual event.

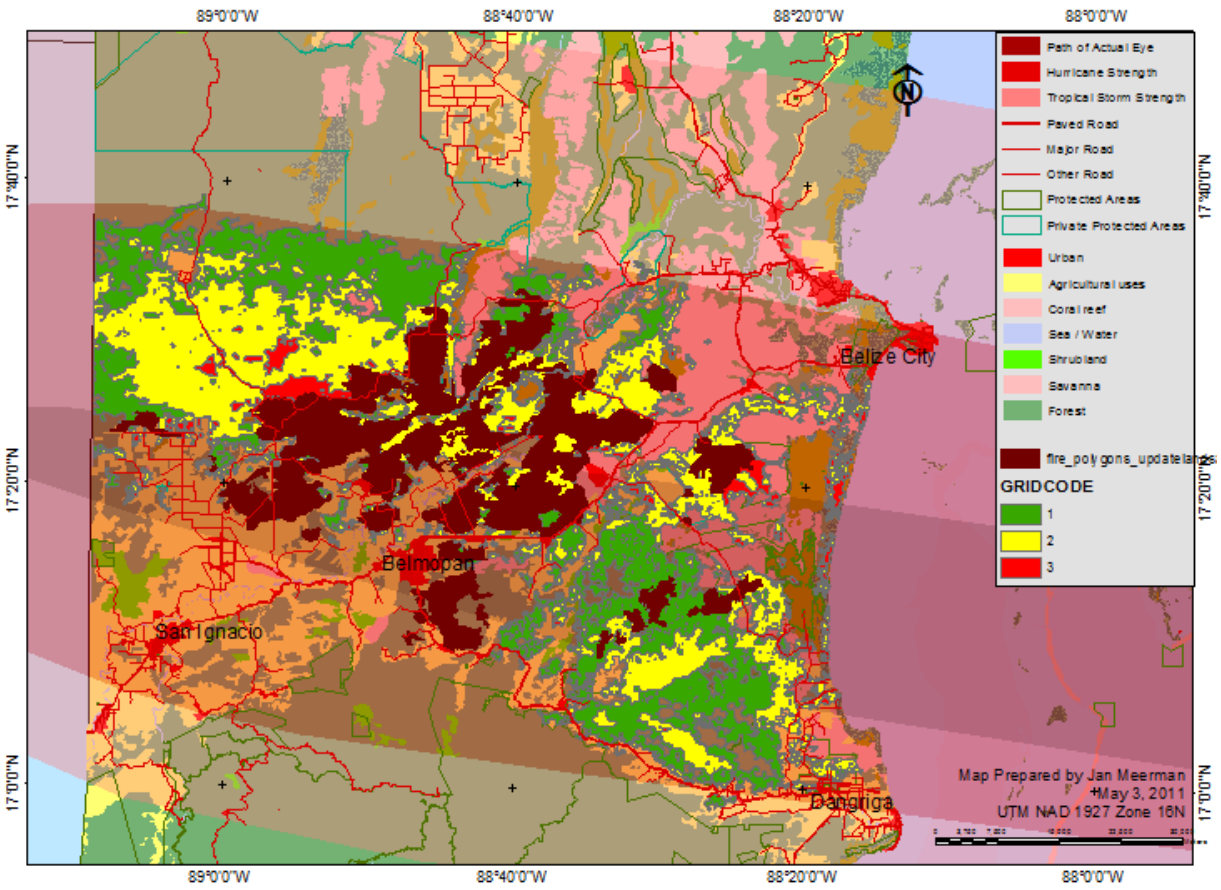


Figure 5. Path of Hurricane Richard in 2010 with damage remote sensing damage analysis from Cathalac superimposed. In dark red, the areas buned in the aftermath of Hurricane Richard. The actual damaged area was much greater than the remote sensing analysis suggested.

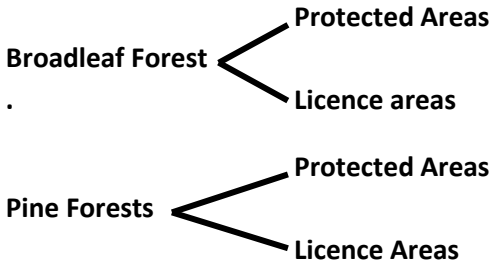
C.4.5 Post aerial reconnaissance analysis

With the help of the photographs taken during the aerial reconnaissance, and possibly combined with remote sensing information we should be able to do a first assessment of the damage. Elements that can be assessed include:

- Damage level
- Heigh/size of the vegetation (see methodology in Cho & Sabido, 2011)
- Abundance of downed logs
- Damage to relevant infrastructure
- Accessibility (road quality)

C.4.6 Damage classes

The first definition which needs to be established is that of 'damage'. But before that we must decide on the forest types which are of interest. From aerial assessments after hurricane Iris only broadleaf and closed pine forest suffered major damage out of all ecosystems in the path of the hurricane. Open pine savannah, mangroves, marshlands, and shrublands did not exhibit any major signs of hurricane damage from the air other than flooding and the toppling of some of the larger trees (particularly Oak). For the purposes of this document, the following broad classes of forest types are of primary interest regarding hurricane.



The following definition of 'damage' on an individual tree basis is recommended for:

Broadleaf forests (all types) and Pine forests (with crown closure exceeding 10%): Any structural degradation of a tree or group of trees as can be ascertained to be caused by wind damage from hurricane and not from any other source or otherwise related to a pre-existing condition. Structural degradation pertains exclusively to the following:

a. removal of branches;

b. removal of whole crowns; c. complete snapping of tree bole below the crown;

d. partial breakage of tree bole below the crown;

e. twisting of tree bole;

f. partial uprooting;

g. complete uprooting;

and does not include:

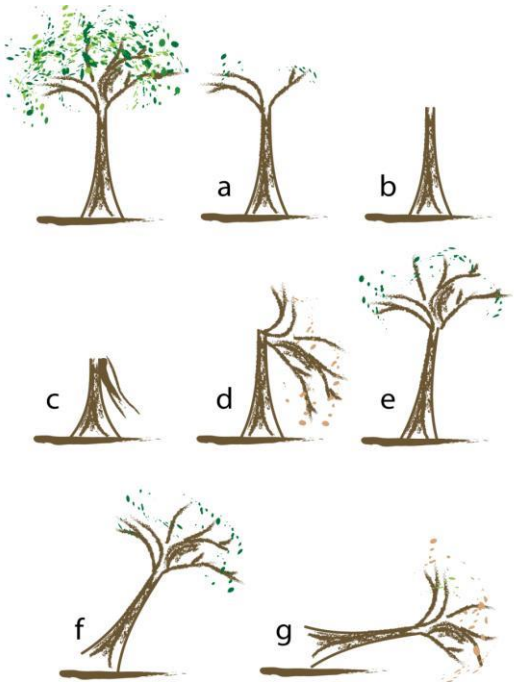


Figure 6. Damage classification from Cho and Sabido, 2011

a. leaning if there is no visible structural damage or partial exposure of roots, and

b. defoliation, because it is not a structural degradation of the tree. The desiccation and removal of leaves by high winds can be remedied by most species within a few days to a few weeks. Furthermore, losing leaves has little relationship to how well broadleaf tree species survive wind damage (Duryea, et al., 2007).

C.4.7 Post flight analysis of Pictures

The first step of post flight data analysis should involve downloading the flight path data from the GPS and using the outer most extent as the 'area of damage'. A quick calculation of area in the GIS can provide an approximate area of damage.

The second step of post-flight data analysis should involve georeferencing each photograph using standard georeferencing capabilities in ArcMAP, in conjunction with GPS points and any landmarks also visible on DOS topographic sheets. There also exists free software that makes it easy to link GPS tracking data (The GPS should have tracking activated) with the digital pictures taken during a flight: http://www.geosetter.de/en/ and https://code.google.com/p/gpicsync/. The principal requirement being that the time on the camera and of the GPS have been synchronized before the start of the flight.

C.4.8 Post Flight Analysis for License Holders

Post-hurricane aerial photography should be visually analyzed in the GIS to produce the following standard outputs (as outlined in Cho & Sabido, 2011) which can be used to determine damage classes:

a. The approximate number of visible trees of any size standing in 100 m2 blocks totalling 5 per photograph and scattered randomly using some random point generation tool in ArcGIS. If possible, snags (crown less trees) should be distinguished from trees with missing branches and from trees will full crowns.

b. The approximate number of visible logs of any size on the ground in the same 100 m2 blocks.

Photogrammetric interpretation of each photograph should result in an approximation of per hectare damage using the damage classes below. For example, for a given 100 m2 block of forest, the approximate damage class can be determined by:

[logs] + [snags] + [trees clearly missing branches] ÷ [logs] + [snags] + [trees clearly missing branches] + [intact trees] = % damage ≈ damage class (severe, moderate or low)

Once all photographs have been analyzed as above, lines of interpretation should be drawn around photographs having the same damage category so that the entire affected area can be apportioned into the different damage classes:

I) Severe - 75% or more of trees per hectare damaged;

2) Moderate: between 75% and 25% of trees per hectare damaged, and

3) Low: 25% or less of trees per hectare damaged.

See Appendix 2 for examples using images from damage caused by hurricanes Iris (2001) and Richard (2010).

Once this stage of the analysis has been complete it is then possible to calculate an estimate of total area of forest damage as it pertains to different damage classes (severe, moderate, low). This process should take no more than 1 week after the aerial assessment has been flown. This step should involve use of the Meerman (2011) revised ecosystem classes to distinguish broadleaf forest from other non-target ecosystems.

Based on pre-hurricane per hectare forest value estimated from existing forest inventory data, economic loss can be calculated by reducing the pre-hurricane per hectare forest value by the percent damage of each class determined from the aerial assessment. For example, if mean pre-hurricane forest value was $3,000 per hectare, then this value in areas which suffered severe damage should be reduced by 75% to be conservative.

This valuation of damage is to be considered a first approximation since the methods are crude. Ideally, this should be followed by ground assessment from which damage quantification and valuation can be tabulated more precisely.

C.4.9 Post Flight Analysis for Protected Area Mangers

In protected areas there may be no need for an actual valuation of lost timber. Instead the focus will be on assessing damage to ecosystems and assets such as roads and buildings. An assessment of road accessibility to tourism assets and infrastructure is particularly important.

C.4.10 Mapping

Once the damage classes have been mapped from the aerial photography it is possible to produce a quick and crude valuation of damage within 2 weeks after the aerial assessment has been flown. Based on pre-hurricane per hectare forest value estimated from existing forest inventory data, economic loss can be calculated by reducing the pre-hurricane per

hectare forest value by the % damage of each class determined from the aerial assessment. Mapping should also include road accessibility.

Important, specifically in hilly terrain will the associated use of a DEM (a 30m resolution DEM is now available for Belize).

C.4.11 Immediate actions

Many needed activities will be conditional to weather conditions. Many field activities won't be feasible until the dry season and most activities that should be carried out now, and not later will most likely be restricted to creating access to key (through) roads and critical infrastructure such as buildings. Each License area and each protected area will face unique conditions.

A general rule should be: If an activity may very probably lead to high environmental impacts (erosion, rutting, unwanted access) and damage to equipment, people and infrastructure as a result of adverse weather conditions, it should be postponed until the dry season.

C.4.12 Reporting

Within 1 week of completion, share Post aerial reconnaissance analysis report including resulting mapping with the Forest Department.

C.5 Post-hurricane second phase (between impact and dry season)

This phase comes into action as once there is a fair idea of the level of damage and carries on until the dry season.

C.5.1 Planning

Based on the outcomes of this first Post-Hurricane phase. It is important to start planning. Many field activities won't be feasible until the dry season. And as such, field activities will have to be postponed until then, giving us time to do thorough planning.

Based on each licence holder's/protected area's unique conditions, the planning will be very individual.

Items to consider are:

- Clearing/repairing access – with the caveat that access that won't be used in the near future is better left alone as it might create unwanted access.
- Inventory of staff and equipment

Make sure you ALWAYS have available the following equipment in good working order.

- Cameras with integrated GPS
- Stand-alone GPS
- Chainsaws
- Machetes and files
- Fire-fighting equipment
- Compasses
- Rite in the rain paper/note books, pencils
- Clipboards
- Batteries/chargers for equipment

Additional equipment specifically for licence holders:

- Diameter tapes
- Tree callipers
- Clinometers or laser range finders

Software needs include

ArcGIS or similar software, including someone that is trained in using it. In the absence of this software and/or capacity identify a consultant that is capable of taking on such a task.

- Ecosystems maps from http://www.biodiversity.bz/mapping/warehouse/

- Digital elevation models from http://www.jspacesystems.or.jp/ersdac/GDEM/E/4.html or anything more accurate (LiDAR if and where available).
- Software to link GPS with digital pictures: http://www.geosetter.de/en/, https://code.google.com/p/gpicsync/.
- Google Earth is increasingly a source of high detail and up to date imagery, even of forested areas.

Heavy equipment

Maintain heavy Equipment for clearing of roads etc. or source a provider in the event of an emergency

- Always keep a tab on what is happening on your boundaries, with particular attention to milpa clearings and other deforestation activities. This monitoring can take place from any angle, from the road, from the air and from satellite imagery.
- Develop fire fighting strategies. This may involve planning access to high risk areas. Do not plan to open access to low risk areas as access may actually create higher fire risk.
- Training. Consider the following training needs.
    - Fire fighting
    - First Aid
    - (Tree) species recognition
    - GPS and compass reading
    - GIS and other software training
- Making alliances: Connect with neighbouring Protected Area/License managers in order to combine forces for the upcoming dry season.
- Start outreach to communities that may affect you (milpa farming, agricultural fires). License holders should team up with protected area managers that have more experience with this.

C.5.2 Salvage considerations

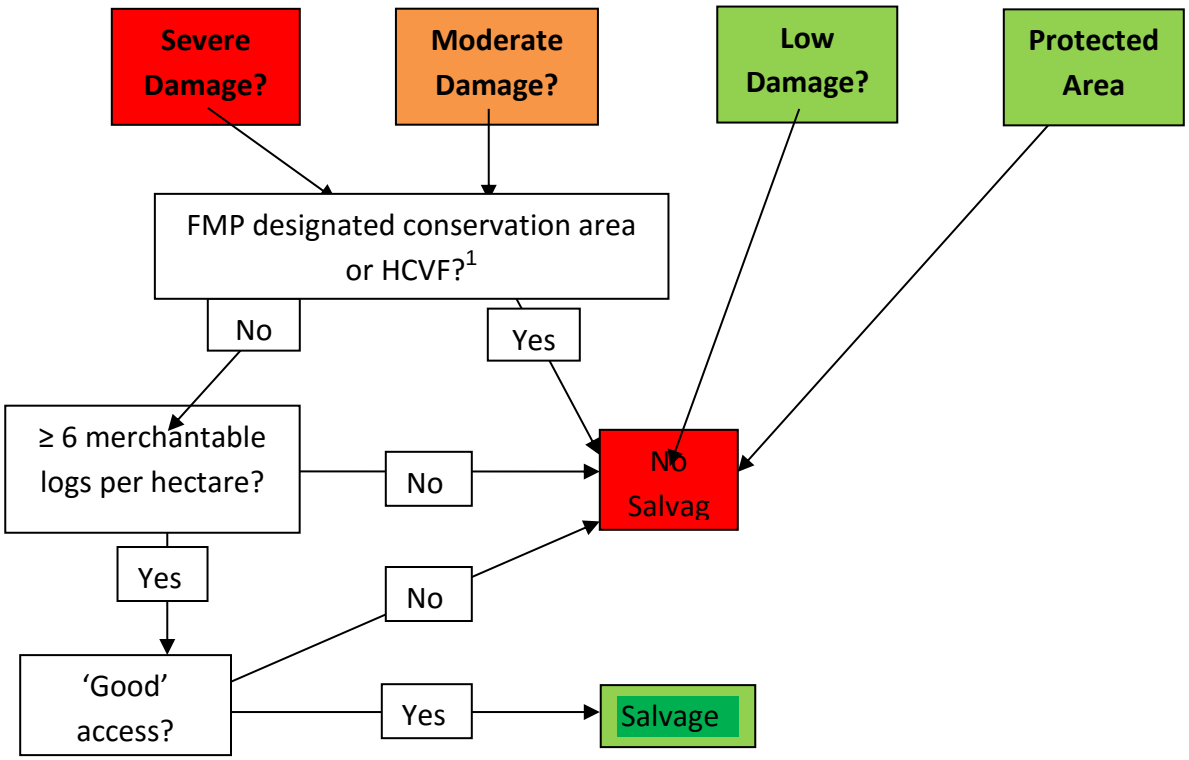
Although there will not be a good moment to do ground assessments until the dry season arrives, this is already the moment to consider salvage operations.

Protected area managers should NOT consider salvage operations for Protected Areas. The focus of Protected Areas should be on the recovery of biodiversity and environmental services. Hurricanes and associated damage should be accepted as part of the whole cycle. Also: salvage operations create a lot of access and debris and actually increase the fire risk.

Besides the quantification and valuation of damage, Upcoming ground survey data (dry season) will further inform the designation of salvage areas. Areas for salvage should be carefully assessed on the ground to avoid causing unnecessary damage to recoverable forests. Because the proportion of survivor trees can be high in areas exhibiting moderate and low damage, only severely damaged areas should be considered for salvage. However, the decision should also be based on the commercial stocking of downed logs. Thus, a number of factors must be considered when deciding salvage areas:

- the potential of the forest to recover ≈ damage class
- the stocking of commercial logs.
- Past logging history

The following decision tree should be used to guide the designation of salvage areas (adapted from Cho & Sabido 2011):



HCVFs are defined as:

- forest areas containing globally, regionally or nationally significant concentrations of biodiversity or cultural heritage (e.g. world heritage sites)
- forest areas that are or contain rare, threatened or endangered ecosystems or species

- forest areas that provide basic services of nature in critical situations (e.g. watershed protection, erosion control)
- forest areas fundamental to meeting basic needs of local communities (e.g. subsistence, health) and/or critical to local communities' traditional cultural identity (areas of cultural, ecological, economic or religious significance identified in cooperation with such local communities)

Important consideration in the analysis is the economic assessment to determine whether salvage operations will actually be cost effective (do they make money or do they cost money).

The areas not eligible for salvage logging according to the diagram above should be considered for continued Sustained Forest Management (SFM) or for conservation depending on site characteristics. If SFM is continued, there should be high emphasis on protection remaining seed sources.

Sustained forest management principles will still apply in hurricane affected areas with regards to the forest services and regeneration even though sustained timber harvesting will not be possible for at least a whole cutting cycle. In this light it would appear that there is a need for new forest regulations to define “hurricane salvage areas”.

Accompany this declaration should be declaration of fire protection areas under the Forest Fire (Protection) Act. This Act requires landowners to prepare fire protection plans and in the even that they are not able to do so, they must let the Forest Department develop the plans.

C.5.3 Fire risk assessment checklist

A principal activity that needs to go hand in hand with any forest management activity is fire prevention and pre-suppression or fire preparedness. These should be planned for and implemented even in years when there are no hurricanes but where meteorological conditions are propitious for a wildfire to spread throughout the license area or property. It is much easier to construct a fire line before a hurricane event than in a hurricane impacted forest.

A post hurricane wild fire risk assessment check list needs to be developed – most likely ignition source, what needs to be done to mitigate, review of fire management capabilities, what kind of training and equipment would be needed for the following dry season? There obviously are urgent and very basic needs that should be addressed. These are in general;

- Fire suppression training
- Assessment of fire hazard and risk and identification of main sources of ignition

- Mitigation of these risks
- Monitoring of weather conditions that contribute to increasing the fire hazard rating.

For this reason it is important to monitor fire risk. Monitoring needs to consider:

- Debris load in the forest
- Terrain
- Proximity of agricultural areas
- Weather conditions
- Actual nearby fires - online MODIS fire products https://firms.modaps.eosdis.nasa.gov/alerts/

Monitoring should start no later than mid-February and continue through the dry season. If the total weekly rainfall (averaged per month) starting from February falls below 18.75 mm per week by the first week of March, arrangements should be made regarding the rapid procurement of necessary firefighting equipment and man power. If relative humidity falls below 65%, public forest fire advisories should be issued by the Forest Department via radio, television, and flyers. Potential sources of fire from adjacent agricultural areas should be identified and the parcel owners should be consulted and guided on how to create proper fire passes around the areas they intend to burn. Constant fire lookout patrols should be conducted by licensees or land owners.

If the progressive mean weekly rainfall continues to remain at or below 18.75 mm at the end of March and relative humidity falls below 45%, the dry season will be approaching anomalously dry conditions which will almost certainly cause any ignition source to spawn a fire that will also spread rapidly through the debris.

C.5.4 Reporting

No later than in January, inform the Forest Department on the following:

- Firefighting masterplan
- Training undertaken
- Alliances formed
- Salvage or no salvage details accompanied by maps where possible/appropriate

C.6 Post-hurricane third phase (dry season)

C.6.1 Damage assessment

Based on Sho and Sabido, 2011, ground damage assessment should be performed in broadleaf forest using 1000 m2 plots (20x50 m) scattered randomly in each damage class determined in section 5.6.1. Ideally the location of the diagnostic plots should coincide with some of the aerial photographs in each damage class. However, this may not be possible for logistical reasons. Sampling of hurricane damage should aim to install 30 randomly located plots for each damage class. Without a measure of variability, it is not feasible at this stage to calculate the required number of plots for a desired precision, but overall there should not be more than 15% difference in the number of plots installed in each damage class. Based on previous experience in hurricane damaged forests no class should have less than 15 plots. In pine forests circular plots of 20 m radius should be utilized instead.

The objective of ground assessment is to obtain a reliable estimate of damage to timber that can be used to inform the issuance of salvage license and to confirm or adjust the valuation of damage obtained from aerial assessments. For this we must assign a lower diameter limit of 25 cm dbh to reduce the sample size and also because trees <25 cm dbh are generally not merchantable. More specifically we must be able to:

1) Measure the proportion of trees felled by the hurricane and the amount of material ≥25 cm on the ground in the plot;
2) From the above, determine the proportion of material ≥25 cm on the ground which consists of species of commercial importance and that is merchantable;
3) Measure the proportion of standing trees ≥25 cm dbh in the plot and within those measure the proportion exhibiting damage caused by the hurricane;
4) From the above, determine the proportion of different categories of damage caused by the hurricane to trees ≥25 cm dbh in the plot.

The following measurement protocol should be followed:

1. The diameter of all standing trees or snags and all freshly fallen trees ≥25 cm in the transect should be recorded and species identified. If species identification is not possible, an 'unknown' will be recorded.
2. Damage to each standing tree or snag should be assessed according to a qualitative two point inspection system of the crown and the stem.
    a. The **first point of inspection** will be the **crown** of a standing tree or snag and either of four levels of damage will be recorded.

i. **Complete crown removal**, meaning that the crown has been completely snapped off or nearly so at any point along its stem. This will be assigned a 1.

ii. Complete branch removal, meaning that although the crown has not been snapped off at any point along the stem all branches from the crown have been broken off. This will be assigned a 2.

iii. Partial branch removal, meaning that at least 1 branch remains on the tree. This will be recorded as a 3.

iv. Full crown intact, meaning that there is no observable damage to the crown. This will be recorded as a 4. Note that complete removal of foliage (leaves) does not constitute crown damage without branch removal.

b. The **second point of inspection** will be the stem of a standing tree or snag and either of three levels of damage will be recorded.

i. Partial stem breakage, meaning that the stem has been burst or snapped but the tree still stands on its own regardless if it is leaning. This will be recorded as a 1.

ii. Bark removal, meaning that any considerable size of bark has been scraped off the stem. This will be given a 2.

iii. No observable stem damage caused by the hurricane will be given a 3.

3. Fallen trees are assessed separately than standing trees. Only freshly fallen trees as a result of the hurricane will be recorded and either of three levels should be recognized.

a. **All completely fallen trees,** meaning that the tree is flat on the ground, will be given a 0 on the field sheet.

b. **Trees which have toppled over with crown or stem damage**, meaning that the tree is not completely on the ground instead leaning on nearby trees or on its own strength but with roots still in the ground and considerable damage to either the crown or stem, will be given a 1.

c. **Trees which have toppled over but with no crown or stem damage**, meaning that the tree is not completely on the ground instead leaning on nearby trees or on its own strength but with roots still in the ground and no observable damage to either the crown or stem, will be given a 2. Note that old logs on the ground should be ignored as they can erroneously increase the fall rate

caused by the hurricane. Even though old Sapodilla or Cabbage Bark logs fallen before the hurricane can be salvaged, it is important to exclude these based on the condition of the bark. Fresh bark will remain on a recently killed tree for around 8 months

The equipment required to conduct the ground survey include:

- 1) diameter tapes;
- 2) 100 m transect tape;
- 3) GPS.

The ground survey can be expected to take 2-4 weeks total if there are no unexpected delays. All data should be recorded in the table provided below according to the examples given. The table can be expanded and printed on individual sheets of paper and carried out into the field.

Quantification and Valuation of Damage from Ground Data:

To quantify damage from the ground survey data we must compare with the mean number of standing trees per hectare ≥25 cm obtained from baseline inventory data. In each plot the number of trees exhibiting no damage should be tallied and extrapolated to per hectare. The damage class for a particular plot can be calculated by:

[baseline standing trees] – [post-hurricane standing undamaged trees] ÷ [baseline standing trees] = % damage ≈ damage class (severe, moderate or low)

Hurricane Damage and Salvage Assessment Field Sheet

Plot Number: Recorder: _____

Date: _____ Damage Class:

Species	Diameter	Fallen Tree	Standing Tree or Snag	
			Crown	Stem
eg. Mahogany	26	---	1	---
eg. Santa Maria	32	0	--	--
eg. Sapodilla	89	--	3	3

The plots should be inputted into the GIS and symbolized according to their damage class after which lines of interpretation can be drawn around similar groups of plots in the same manner as was done for aerial photographs. Both of these methods should agree with results of the aerial survey. But the ground-based results will be more precise and should provide the final estimates of damage area.

To quantify damage we must not include trees which can recover, i.e. those trees having ≥1 branch. This factor is overlooked in the valuation of damage using aerial photography thereby leading to overestimation, thus the result from ground survey should provide final estimates of the value of damage caused to forests. However, valuing damage from ground survey is more computationally demanding but more precise because it involves a direct comparison of before and after ratios. The most recent inventory data from the nearest comparable location should be used in this calculation. First, mean per hectare volume of commercial species ≥25 cm must be calculated if not readily available from a management plan. If the data is more than 5 years old, the volumes must be forwarded to present using a known mean volumetric increment averaged for all species of trees ≥25 cm. A mean market value for all species should then be applied to the mean per hectare commercial volume in order to obtain per hectare value for standing forests before the hurricane. Because we do not know the level of pre-existing damage in plots we should assume that it is nil, i.e. no commercial logs and no tree damage.

Next, we must recalculate damage classes while excluding trees with ≥1 remaining branch. Note that the results differ from the damage classes assigned to ground plots during the quantification of damage because here we take into account tree survivorship and not only tree damage. For example,

[Pre-hurricane mean no. standing trees ≥25 cm per hectare] – [Post-hurricane mean no. standing trees ≥25 cm (with ≥1 branch) per hectare] ÷ [Pre-hurricane mean no. standing trees ≥25 cm per hectare] = percent damage ≈ commercial damage class (severe, moderate or low).

Each plot should be assigned to a commercial damage class and then inputted into the GIS and symbolized according to their commercial damage class after which lines of interpretation can be drawn around similar groups of plots. The total area of each commercial damage class can be calculated in the GIS. The results will differ from the areas determined from aerial survey and from the damage mapping using ground survey, because here we are deriving area and magnitude of damage to commercial stems as opposed to total damage.

Next, the per hectare value for standing forests should be multiplied by the area of each commercial damage class. The total value for each of the three areas should be multiplied by the respective damage percent. The sum will be the value of commercial damage caused by the hurricane.

The following definition of ‘damage’ on an area basis is recommended for:

Broadleaf forests (all types) and Pine forests (with crown closure exceeding 10%): Any cluster of trees ≥0.5 ha in size exhibiting damage according the following density per hectare:

1) Severe - 75% or more of trees per hectare damaged;
2) Moderate: less than 75% and more than 25% of trees per hectare damaged, and
3) Low: 25% or less of trees per hectare damaged.

The above are considered 'damage classes'. These definitions do not rely on the percent of trees standing because it is easier to count fallen logs than standing leafless trees from the air.

C.6.2 Salvage logging

The dry season is the time for salvage logging operations. See C.5.2. Salvage Logging Considerations.

C.6.3 Clearing of assets

Any assets that have not been cleared need to be cleared now. Note that it is unwise to unnecessary clear roads that won't be used this season. Open roads may create unwanted access and even contribute to fire risk.

C.6.4 Activate firefighting strategies

Ideally, there should be weather monitoring performed within hurricane affected areas. A good spacing for monitoring stations is 50 km. However, because the Hydromet service has good coverage across the country it may be possible to effectively rely on Hydromet rain gauges to inform total weekly rainfall. But it is also necessary to monitor relative humidity which unlike rainfall, is governed by localized terrain, vegetation, temperature and wind dynamics. In this case, relative humidity should be monitored at a higher temporal and spatial resolution than rainfall.

Ideally each SFM forest entity (licensee or private property owner) should be encouraged to monitor relative humidity at their respective bush camp site. Monitoring of total weekly rainfall (averaged per month) and daily average humidity should begin in February and continue routinely throughout the dry season.

If the total weekly rainfall (averaged per month) starting from February falls below 18.75 mm per week by the first week of March, arrangements should be made regarding the rapid procurement of necessary firefighting equipment and man power. If relative humidity falls

below 65%, public forest fire advisories should be issued by the Forest Department via radio, television, and flyers. Potential sources of fire from adjacent agricultural areas should be identified and the parcel owners should be consulted and guided on how to create proper fire passes around the areas they intend to burn. Constant fire lookout patrols should be conducted by licensees or land owners. Think of the online resources: https://firms.modaps.eosdis.nasa.gov/alerts/

If the progressive mean weekly rainfall continues to remain at or below 18.75 mm at the end of March and relative humidity falls below 45%, the dry season will be approaching anomalously dry conditions which will almost certainly cause any ignition source to spawn a fire that will also spread rapidly through the debris.

C.6.5 Fight fires

When fires do occur it is important to suppress them as soon as possible, even when this means suppressing them before they reach your Licence/protected area. This is the time to activate your alliances.

C.6.6 Reporting

Immediate upon completion share the Damage Assessment report with the Forest Department. IMPORTANT, the damage assessment needs to be approved by the Forest Department BEFORE any salvage activities are being implemented!

Any firefighting reports need to be communicated with the Forest Department on a daily basis.

C.7 Post-hurricane fourth phase checklist (after dry season)

Follow phase two and three methodologies until salvage completed and fire risk deemed "normal"

Within 2 months after the rainy season has started; present status report to the Forest Department. This Status Report should include.

- Activities undertaken during the past season
- Review of damage assessment
- Status of any salvage operations
- Lessons learned (what worked and what did not)
- Activities planned for the coming season(s).

D. Appendix 1: List of Stakeholders

Area	Company	Phone	Contact person
Mountain Pine Ridge	Pine Lumber Co	824 3255 / 610-3224	Amin Bedran
Chiquibul Forest reserve	Bull Ridge	825 3255 / 610-3224	Amin Bedran
Deep River Forest reserve	Thomas Gomez & Son	661 0780 / 722-2532	
Manatee Forest reserve	New River Enterprise	322 3372/3373 2225	Joe Loskot
Rio Bravo Conservation &management area	Program for Belize	227 5616 / 227-5611 / 604-7819	Ramon Pacheco
Southern Coastal plains	Wood Depot	822 0864 / 822-2387	
laguna Seca	Laguna Seca	823 0426	Jeff Roberson
yalbac Ranch &Cattle Co	yalbac Ranch	823 0426	Jeff Roberson
Maya Mountain Forest Reserve	Charles Sellers	668 4789	Charles Sellers
Balam Jungle	Balam Jungle	628 5300	
Gallon Jug	Gallon Jug	600 0684	Alan Jeal
Mountain Pine Ridge	Ben Recinos	667 2218	Ben Recinos
South	TIDE	722-2431/2274 - 732-4708	Mario Muschamp
South	YCT	722-0108/609-6960	Bartolo Teul
South	SATIIM	722-0103	Martin Cus
General	Belize Audubon	Belize City	Dominique Lizama
FWCFR	CSFI		Heron Moreno
Chiquibul	FCD		Rafael Manzanero

E. Appendix 2: Hurricane Damage Images

Aguacaliente: Swampforest after Hurricane Iris.

Aguacaliente. Detail of swamp forest after hurricane Iris. Based on the formula [logs] + [snags] + [trees clearly missing branches] ÷ [logs] + [snags] + [trees clearly missing branches] + [intact trees] = % damage, this would a damage level of approximately 95% and be classified as "Severe damage"

Hill forest near Aguacate

Detail of Hill Forest near Aguacate. Note that there are clearly 2 different damage classes. There are only a few logs and snags visible but it is difficult to determine from the picture whether the trees are missing branches or merely defoliated. This distinction would put the damage class either in “Severe” or “moderate”. The areas in the valleys should be classified as “low damage”

Lowland forest near Blue Creek, Toledo after hurricane Iris.

Detail of lowland forest near Blue Creek, Toledo after hurricane Iris. Most trees are reduced to mere snags. This is “severe” damage.

Hill forest in the Columbia River Forest Reserve after hurricane Iris.

Detail of Hill forest in the Columbia River Forest Reserve after hurricane Iris. Individual logs not visible. But a large number of trees are reduced to snags. Yet, this is a complicated picture. The damage level is borderline “severe/moderate” with patches of low damage.

Monkey River after hurricane Iris.

Monkey River after hurricane Iris. Virtually all trees reduced to snags. Even without counting, this a clear case of “severe” damage.

Yalbac after Hurricane Richard

Detail of Yalbac after Hurricane Richard. Based on the formula [logs] + [snags] + [trees clearly missing branches] ÷ [logs] + [snags] + [trees clearly missing branches] + [intact trees] = % damage, this would a damage level of approximately 76% and be classified as “Severe damage” but this is a borderline case with the level of damage to “intact” trees difficult to verify.

Yalbac after Hurricane Richard

Detail of Yalbac after Hurricane Richard. Most of the trees down or reduced to snags. Clearly to be classified as “Severe damage”.

Yalbac after Hurricane Richard and 2011 wildfire

Detail of Yalbac after Hurricane Richard and 2011 wildfire. Logs have been reduced to ashes (white patches). Many Cohune palms had their crown recovered after the hurricane but now have burned.

F. Appendix 3: Literature Consulted

Askinsm R. A., D. N. Ewert, 1991. Impact of Hurricane Hugo on Bird Populations on St. John, US. Virgin Islands. Biotropical 23 (4): 481-487.

Bascope Sarue, S.F. 2010. Aspectos Socioeconomicos del modelo de foresteria communitarian post-Huracan Felix en la Region Autonoma del Atlantico Norte – RAAN, Nicaragua. Tesis Catie. 148 pp.

Beard et al 2005. Structural and functional responses of a subtropical forest to 10 years of hurricanes and droughts. Ecol. Mono. 75: 345–361.

Boose, E.R., Foster, D.R., and Fluet, M. 1994. Hurricane Impacts to Tropical and Temperate Forest Landscapes. Ecol. Mono. 64: 370-400.

Boucher, D.H., Vandermeer, J.H., Mallona, M.A., Zamora, N., and Perfecto, I. 1994. Resistance and resilience in a directly regenerating rainforest: Nicaraguan trees of the Vochysiaceae after Hurricane Joan. For. Eco. Manage. 68: 127-136.

Browkaw, N.V.L. and L.R. Walker. Summary of Effects on Hurricanes on Vegetation. Biotropica 23 (4): 442-2447.

Burslem, D.F.R.P., Whitmore, T.C. and Brown, G.C. 2000. Short-term e€ects of cyclone impact and long-term recovery of tropical rain forest on Kolombangara, Solomon Islands. J. Ecol. 88: 1063-1078.

Chazdon, R.L. 2003. Tropical forest recovery: legacies of human impact and natural disturbances. Persp. Plant Ecol. Evol. Syst. 6: 51-71.

Cho, P. & O.A. Sabido. 2011. A strategy to guide the response to Hurricane Damage in Belize's Forests. Catie-Forest Department. 58 pp.

Cho. P. 2013. An Investigation of tropical forest response to hurricane disturbance with evidence from long-term plots and earth observation in Central America. Lancaster Environmental Centre. Lancaster University. 207 pp.

Cochrane, M.A. 2003. Fire science for rainforests. Nature. 421: 91319.

Cochrane, M.A. and Schulze, M.D. 1999. Fire as a Recurrent Event in Tropical Forests of the Eastern Amazon: Effects on Forest Structure, Biomass, and Species Composition. BIOTROPICA 31: 2-16.

Cochrane, M.A., Alencar, A., Schulze, M.D., Souza, C.M., Nepstad, D.C., Lefebvre, P. and Davidson, E.A. 1999. Positive Feedbacks in the Fire Dynamic of Closed Canopy. Tropical Forests. Science. 284: 1832- 1835.

Friesner, J. 1993. Hurricanes and the Forests of Belize. Forest Department, 20 pp.

Gardner, T. A. et al. 2008. The cost-effectiveness of biodiversity surveys in tropical forests. Ecology letters 11: 139-150.

Liu, K.B., H. Lu & C. Shen. 2007. A 1200-year proxy record of hurricanes and fires from the Gulf of Mexico Coast: Testing the hypothesis of hurricane-fire interactions.

Lugo, A.E. 2008. Visible and invisible effects of hurricanes on forest ecosystems: an international review. Austral Ecol. 33: 368–398.

McGinley, K., Arendt, W., Bauer, J., and Pallais, J.M.Z. 2009. Nicaragua country analysis of tropical forests and biological diversity FAA 118/119 assessment. USAID, Nicaragua.

Meerman, J. 2004. Rapid Ecological Assessment – Columbia River Forest Reserve past Hurricane Iris. Report to Ya'axche Wildlife Trust. 53 pp.

Meerman, J. C. 2001. A first Assessment of Damage to terrestrial ecosystems in Southern Belize as caused by Hurricane Iris of October 8, 2001. Report to the Foreste Department. 8 pp.

Meerman, J.C. 2011. Provisional Report on the Belize 2011 Wildfires. Aftermath of Hurricane Richard. Belize Tropical Forest Studies, 11 pp.

Metcalfe, D.J., Bradford, M.G. and Ford, A.J. 2008. Cyclone damage to tropical rain forests: Species- and community-level impacts. Austral Ecol. 33: 432–441.

Pacheco. R. 2011. The Rio Bravo Conservation and Management Area, Fire Report 2011. Internal Report 16 pp.

Snook, L.K. 1996. Catastrophic disturbance, logging and the ecology of mahogany (*Swietenia macrophylla* King): grounds for listing a major tropical timber species in CITES. Bot. J. Linnean Society. 122: 35–46.

Turton, S. 2008. Cyclones Larry and Monica: ecological effects of two major disturbance events. Austral Ecol. 33: 365–367.

Vandermeer, J., Boucher, D., Perfecto, I., and Granzow de la Cerda, I. 1996. A Theory of Disturbance and Species Diversity: Evidence from Nicaragua After Hurricane Joan. Biotropica. 28: 600-613.

Vandermeer, J., Granzow de la Cerda, I., Boucher, D., Perfecto, I. and Ruiz, J. 2000. Hurricane Disturbance and Tropical Tree Species Diversity. Science. 290: 788-791.

Waide, R. B. 1991. Summary of the Response of Animal Populations to Hurricanes in the Caribbean. Biotropica 23(4): 508-512.

Whigham, D.F., I. Olmsted., E. Cabrera Cano, M.E. Harmon. 1991. The impact of Hurricane Gilbert on Trees, Litterfall and Woody Debris in a Dry Tropical Forest in the Northeastern Yucatan Peninsula. Biotropica 23 (4): 434-441.

Wiley, J.W. & J. M. Wundeerle, Jr. 1993. The effects of Hurricanes on birds, with special reference to Caribbean Islands. Bird Conservation International 3: 319-349

Wolffsohn. A. Post Hurricane Forest Fires in British Honduras. 6pp.