WORKSHOP SERIES NO.7

THE OFFSHORE EFFECTS OF CYCLONE WINIFRED

PROCEEDINGS OF A WORKSHOP HELD AT THE TOWNSVILLE INTERNATIONAL HOTEL, FRIDAY, JUNE 20, 1986

EDITOR: I.M. DUTTON

ISSN 0156-5842
ISBN 0-642-52529-3
Published by GBRMPA, 1986

TABLE OF CONTENTS

Part A : WORKSHOP PROCEEDINGS

PART B : WORKSHOP PAPERS

APPENDICES

EXECUTIVE SUMMARY

This report outlines the proceedings and findings of a workshop on the offshore effects of tropical cyclone Winifred. The cyclone crossed the North Queensland coast south of Innisfail on February 1, 1986. The workshop was held at the Townsville International Hotel on Friday, June 20, 1986.

The workshop had two principal objectives;

- to review what was learned from studies of the offshore effects of cyclone Winifred; and
- to review the significance of those findings in the context of our understanding and management of the Great Barrier Reef Region.

Nineteen reports and papers were presented in respect of the first objective, covering a range of scientific and management-oriented topics. Each of these contributed to the second objective. This was considered in detail by the workshop under the following headings:

- **Biophysical and ecological significance.** While Winifred was not an exceptional cyclone (rated 3 on the five level Saffir-Simpson scale), follow-up studies yielded new insights into the functioning of the Great Barrier Reef system. Short-term phenomena, such as nutrient release from lagoonal sediments, were observed which may have significant longer term implications for the functioning of the Great Barrier Reef.
- **Socio-economic significance.** Little data was obtained on the offshore socio-economic impacts of Winifred. Although reports presented noted that damage to structures and facilities was minimal. Data obtained to date on post-disaster response indicates that local residents and visitors would have experienced severe, short term disruption.
- **Scientific understanding of the Great Barrier Reef.** Winifred provided an excellent opportunity to evaluate the effects of an extreme, short-term phenomena. Measurement and evaluation of those effects was greatly facilitated by the availability of "baseline" information on aspects of the impacted area in the form of data obtained from studies undertaken in the week preceding the cyclone. New information was obtained on short and mid-term processes; however, understanding of this will be limited until longer term and comparative data are available.
- **Human use.** Human use of the offshore areas was severely disrupted in the short-term by Winifred. The extensive damage to some reefs and inter-reef areas may cause some disruption to tourism and fisheries operations between Fitzroy and Hinchinbrook Islands.

- **Management of the Great Barrier Reef.** Winifred reinforced the notion that cyclones are one of the most significant forces shaping the Great Barrier Reef. Concern was expressed that, in planning for human use of offshore areas, care should be taken that the proposed activity does not interfere with the inherent ability of natural systems to recover from extreme damage, such as is caused by cyclones.

- **Research response.** It was noted that the research response to Winifred was the best yet achieved. However, major deficiencies exist in many areas, particularly socio-economic studies. Longer term, follow-up studies are also needed on processes such as the potential occurrence of ciguatera outbreaks. In order to improve response to future cyclones, three recommendations were put forward by the workshop:

  (1) A meeting of nominated heads of involved institutions be held to determine individual and collective responsibilities and requirements with a view to developing a co-ordinated response system.

  (2) The Great Barrier Reef Marine Park Authority should co-ordinate a multidisciplinary committee to oversee research activities after natural disasters, especially to organise long-term studies.

  (3) A source of funding be identified to enable rapid response to future incidents. This should be considered in the context of both points above.

Footnotes:

On June 3, 1986, the Commonwealth Government provided $30 000 to the Johnstone Shire Council and the James Cook University for a project designed to develop practical approaches to disaster management. This will, at least in part, redress some of the deficiencies noted above.

On August 25, 1986, the meeting recommended in (1) above was held. This meeting was attended by the heads of the three principal institutions; the Great Barrier Reef Marine Park Authority, The Australian Institute of Marine Science, and the James Cook University. The meeting agreed that the Authority should proceed with establishing a committee to plan for disaster response as recommended. Where possible, any plan(s) should make provision for involvement of appropriate research groups, particularly the Centre for Disaster Studies at James Cook University.

ACKNOWLEDGEMENTS

The Authority gratefully acknowledges the valuable contribution made by all workshop participants. As the first such workshop held on the offshore effects of a cyclone in the Great Barrier Reef Region, the workshop and its findings represent an important reference point in our understanding and management of the Great Barrier Reef Marine Park.

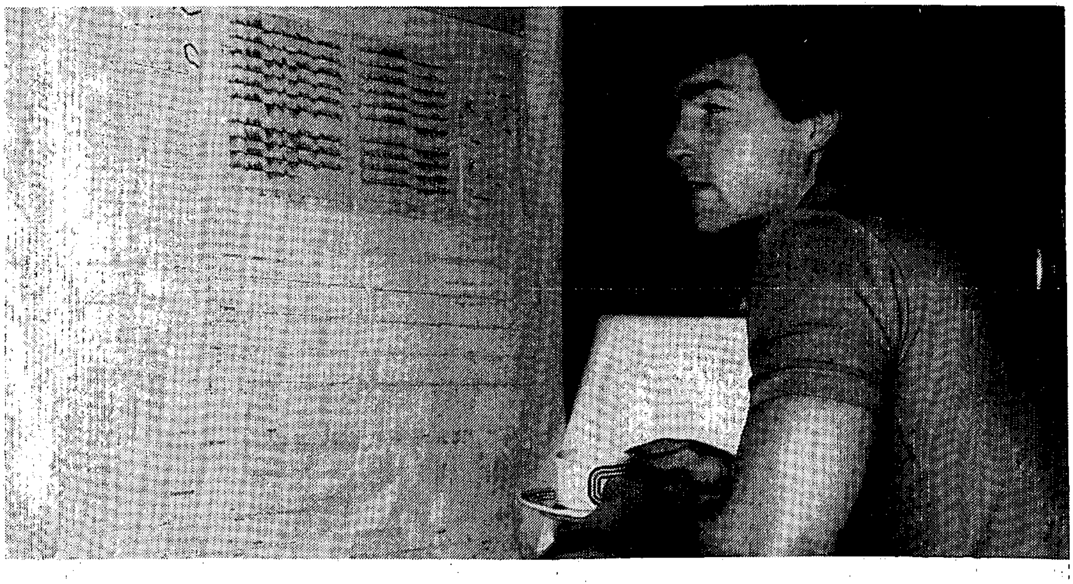
The Authority would particularly like to recognise the assistance of the workshop speakers, and others who provided background information for the discussions. The guidance of the overall Chairpersons; Dr Don Kinsey, and Dr Wendy Craik; and of the Small Group Leaders; Dr Leon Zann, Associate Professor David Hopley, Professor Kevin Stark, and Emeritus Professor John Oliver; played a major part in ensuring the workshop objectives were met.

Bruce Miller-Smith and Christine Dalliston provided the logistical support for the workshop and preparation of this report. Assistance with editing and graphics for this publication was provided by David Donohue. Special mention should also be made of the assistance of Beryl Dennis and Kerryn Wiseman who carefully typed the report.

Further information on any aspect of this report, or the workshop generally, may be obtained from:

The Assistant Executive Officer,
Research and Monitoring Section,
Great Barrier Reef Marine Park Authority,
P.O. Box 1379,
TOWNSVILLE, QLD 4810

Part A



1. INTRODUCTION

Cyclones have long been recognised as a major influence on the Great Barrier Reef, the world's largest tract of coral reef. However, until comparatively recently, the effects of cyclones on the offshore parts of the Great Barrier Reef Region have not been scientifically assessed. This reflects a number of influences; in particular the fact that the effects of cyclones are of most concern in areas of human settlement and permanent activity. It also reflects the comparative difficulty in determining the offshore effects, as they are generally not as obvious as the onshore effects.

When cyclone Winifred crossed the North Queensland coast south of Innisfail on February 1, 1986, it presented a rare, if not unique, opportunity to evaluate offshore effects. This was largely because of the presence of scientific equipment and personnel in the vicinity of the cyclone path. Scientists from the Australian Institute of Marine Science (AIMS) and James Cook University of North Queensland (JCU) had been working in the area offshore from Innisfail during the week prior to the cyclone crossing the coast. In the aftermath of the cyclone, they were able to resurvey the same area and thus obtain the first, albeit preliminary, scientific evaluation of the offshore effects of a cyclone in the Great Barrier Reef Region.

The Great Barrier Reef Marine Park Authority (GBRMPA), which has primary responsibility for the care and development of a Marine Park in the Great Barrier Reef Region recognised and supported this research endeavour by;

- arranging for an aerial reconnaissance survey of the coastal and offshore area by staff of the Queensland National Parks and Wildlife Service (Q.NPWS), and by AIMS and JCU, and GBRMPA staff. A report of that survey is presented in Part C of this report;

- participating in, and providing financial and logistical support to, vessel-based surveys of offshore reefs and waters; and

- arranging for compilation of damage assessment reports and surveys in concert with the Q.NPWS, which is the agency responsible for day-to-day management of the Great Barrier Reef Marine Park. These are also reported in Part C of this report.

As a result of these studies, it was recognised that it would be very useful to management of, and research into, the Great Barrier Reef system to develop an overview of the effects of cyclone Winifred. Accordingly, the Authority arranged for a workshop to be held once all preliminary information was compiled and analysed.

The workshop was held in Townsville on June 20, 1986, and involved participants from GBRMPA, AIMS, JCU, Q.NPWS, other State and local government agencies, consultants, industry, and the general public. A complete list of participants is given in Appendix I.

The workshop had two principal objectives;

- to review what was learned from studies of the offshore effects of cyclone Winifred; and

- to review the significance of those findings in the context of our understanding and management of the Great Barrier Reef Region.

Allied with the second objective are a range of issues which are fundamental to determining the significance of Winifred. These were considered in detail in the small group discussion sessions held during the workshop, and include;

- assessment of whether Winifred was a significant event (in reference to natural phenomena and use of the Great Barrier Reef);

- how Winifred affected our understanding and use of the Great Barrier Reef;

- how information obtained from studies of Winifred can be applied to management of the Great Barrier Reef Marine Park;

- whether the scientific response and studies undertaken were adequate, and if not, in what respects were they inadequate; and

- what longer term and/or follow-up studies are necessary or desirable.

Appendix II outlines the workshop program. The detailed small group briefs for these topics are presented in Appendix III. Participants in each group are noted in Appendix I.

This report is structured to reflect the workshop findings in relation to the above objectives and discussion topics. Part A incorporates the workshop findings and recommendations in relation to both objectives and the discussion topics. It was compiled largely from the reports of the small group discussions.

Part B sets out the findings of studies undertaken on cyclone Winifred. Many of the papers are brief reviews of aspects of the range of offshore and coastal effects, as further analysis and/or study is required. It is anticipated that further reports may be produced by some of the authors once this additional work is undertaken.

All references cited in Part A refer to papers in Part B. To complement the information set out in Parts A and B of this report, a range of supporting material has also been prepared and incorporated in Part C. This material includes damage reports not presented to the workshop, and a short annotated bibliography on the effects of cyclones.

2. THE SIGNIFICANCE OF CYCLONE WINIFRED

Kelleher and Dutton describe cyclones as one of the most significant natural influences shaping the Great Barrier Reef. They noted that the significance of cyclones has many dimensions, including;

- ecological and biophysical;
- socio-economic (including engineering); and
- managerial.

With this framework established, the workshop therefore considered the question of "significance" in terms of identifying ecological, biophysical and socio-economic aspects with a view to obtaining an appreciation of management aspects.

2.1 Biological and ecological significance

The groups which considered the biophysical and ecological significance of cyclone Winifred agreed that, compared with other cyclonic events which have affected or may in future affect the Great Barrier Reef, Winifred was not particularly significant. It ranked as a category 3 cyclone on the 1 to 5 Saffir-Simpson scale, and thus was characteristic of many of the cyclones which have been recorded since European settlement of Australia. Winifred crossed the shelf during low tide, and this may have attenuated its effect on reefs and waters in the path. However, it was noted that no major changes to the shoreline of offshore islands or the mainland coast resulted. None of the signs of gross morphological change such as complete submergence of cays, establishment of ramparts or generation of emergent reef blocks were observed.

Changes in the physical character of the affected area were limited to minor cay and beach erosion and the rearrangement of part of the sediment bed of the lagoon between the mainland and offshore reefs. The latter observation was considered particularly significant as it gave an indication of the massive sorting processes which occur as a result of cyclones. From studies by Sandstrom, Bode and Wolanski, and Birtles, participants recognised that the lagoonal sediments may play a greater role than was previously realised in productivity in Reef waters and on the reef proper.

This finding has important implications for understanding cross-shelf geochemical and ecological processes, although it was noted that more detailed longer term studies are needed to develop a full appreciation of the significance of this observation. In this context, the relationship between cyclones and crown of thorns starfish (*Acanthaster planci*) damage was mentioned as a topic requiring special attention. The area of reefs directly affected by the cyclone had recently been extensively affected by crown of thorns starfish outbreaks. It is expected that the *A. planci* research program currently underway may lead to a better definition of this cumulative impact.

Participants noted that the geographic influence of the bio-physical impacts of Winifred was largely restricted to the area between Fitzroy and Hinchinbrook Islands. Studies at Green Island by Harriott and Fisk recorded slight impact on corals and coral regeneration, and may have yielded new insights into the mechanical tolerance of corals. For example, little damage was recorded in areas exposed to wind gusts of up to 100 km/hr. It was also postulated that damage to the coral community in this area may have been restricted because of the early successional stage of corals due to past crown of thorns damage.

Similarily, Lewis, Burke, and Gillespie noted that, at Sudbury Reef, there is little evidence to date of an increase in ciguatera levels; a phenomenon often associated with reef disturbance. They caution however, that it may take up to 18 months for this phenomena to be manifested.

In terms of coastal and island systems, Muir, and Blackman and Winter observed major impacts on some flora and fauna. Extensive defoliation of emergent vegetation was recorded, resulting in loss of habitat for fauna such as Cassowaries and Torresian Imperial Pigeons. By contrast, Smith noted that Winifred caused little damage to mangrove communities compared with cyclone Kathy which crossed the northern Australian coast from the Gulf of Carpentaria in 1984. Participants agreed that this was most likely due to the difference in windspeed between the two cyclones (Kathy was 15 to 25 km/hr higher on average).

The overall conclusion of the discussion groups on biophysical and ecological aspects was that Winifred provided new insights into the functioning of the Great Barrier Reef system. The studies undertaken were possible only because of the ready availability of scientific expertise and logistical support. These studies confirmed the potential importance of short-term extreme events in the long-term maintenance and development of the Great Barrier Reef. Participants noted, however, that interpretation of the results obtained is severely limited by lack of data prior to, and during the cyclone event, and by the lack of understanding of the Great Barrier Reef system.

2.2 Socio-economic significance

The socio-economic significance of cyclone Winifred appears to be poorly understood, but compared with onshore effects, relatively minor. As Part B of this report suggests, there is a dearth of information on socio-economic effects. The reports available describe minor damage to some resort and offshore tourist infrastructure (moorings for example). Some damage to clam mariculture operations was also noted, this may result in a delay in breeding and experimental studies.

Participants noted that short-term disruption did occur to the two main offshore industries, commercial fishing and tourism. They agreed, however, that the long term effects are likely to be relatively minor, with the possible exception of effects on public perception and behaviour. The latter effect was described by Foley and Thorpe, mainly in terms of the experience of a sense of devastation among local residents. They noted that there is a three-part effect on cyclone victims; economic, social, and psychological, with the latter most enduring.

Follow-up studies of cyclone-affected coastal communities by JCU researchers will focus on this aspect, and may give insights into broader community attitudes relevant to use of the Great Barrier Reef (in the vein of, "when do locals and/or tourists feel safe to 'go back into the water'?").

The workshop noted that engineering design standards for offshore infrastructure appear adequate, although further attention may need to be paid to new types of activities such as mariculture, to ensure that design standards take account of all possible types of impact. Attention should be paid to operational procedures in the event of a cyclone warning to ensure, for example, that an adequate supply of seawater will be available during the cyclone, or that offshore facilities are adequately protected.

Most authorites have adopted category 3 of the Saffir-Simpson scale as the design standard, and in few instances were there failures of structures built to this requirement. No major failures of offshore structures was recorded by McClymont. However, Walker noted that in some onshore areas, local topographic influences had concentrated the destructive effects of Winifred. This finding may have implications for offshore design.

3. EFFECTS OF WINIFRED ON UNDERSTANDING

3.1 Scientific understanding

Winifred represented a major research opportunity in that it provided scientists with the opportunity to evaluate the effects of an extreme, albeit short-term, phenomena on the Great Barrier Reef. The extent to which this opportunity could be translated into knowledge and understanding was, however, limited by;

- the general lack of understanding of the Great Barrier Reef system, although the availability of recent survey data on some aspects of the offshore environment did enable "state of the art" assessments;
- the lack of survey techniques, design and resources. It was noted for example, that the scientific response would have been enhanced by the availability of a contingency plan for scientific response; and
- the inability to plan and implement a comprehensive research program, which is related to the factor above.

In the latter respect particularly, it was noted that the benefit of Winifred to scientific understanding of the Great Barrier Reef system may only be realised in the long-term through carefully designed longitudinal studies of specific phenomena. An example of this, as noted by Lewis, Burke and Gillespie, is the necessity to monitor affected reefs for up to two years after a cyclonic event before clear conclusions about the effects on ciguatera levels can be drawn.

Despite the limitations imposed by these points, it was agreed that Winifred provided a significant incremental increase in our understanding of offshore cyclonic impacts. It was suggested in this context that it may be possible for research planning purposes to recognise various levels of impact, as set out below:

- **Primary impacts:** short-term (within a day) extreme changes (often visually observable); such as changes in reef, cay, or coastline morphology; destruction of coral or vegetation; change in, loss, or displacement of fauna;
- **Secondary impacts:** mid-term (one week to one year), obvious effects (visual and equipment based measurement) such as increased turbidity, nutrient resuspension, changes in current patterns, plant, and animal succession; and
- **Tertiary impacts:** long-term (more than one year) subtle effects (detectable only by experimentation and/or monitoring) such as changes in productivity, interspecies competition (for example, crown of thorns starfish), development of new formations (micro atolls), and features (sand spits).

Based on the information presented to the workshop, it was determined that studies of Winifred had confirmed previous knowledge about the types of "primary" impacts and the processes involved in those impacts. More importantly, studies yielded new insights and information on the "secondary" and "tertiary" impacts of tropical cyclones. In particular, the workshop indentified the work of Carter et al., Sandstrom, and Bode as useful in terms of providing new insights into the functioning of the Great Barrier Reef system.

From a management perspective, it was also noted that Winifred provided new opportunities to identify how the level of change/damage caused by cyclones may have been affected by human activity. For example, Blackman and Winter expressed concern that the effects of land clearing on wildlife may have made some species more vulnerable to catastrophic, short-term influences such as occur during cyclones.

3.2 Human use

Differences between the short-term and long-term effects of cyclones on human use of the coastal and offshore areas were identified. Short-term effects such as damage to structures, disruption to services and activities (tourism and fishing operations for instance), loss of amenity, and emotional impacts have been identified. Very little data on the extent or significance of these impacts was obtained, especially when compared with data available on "onshore" impacts. It was noted, for example, that local patterns of recreational boating use were altered for several weeks after the cyclone. This reflects both a typical disaster response by locals and the prevalent physical conditions (for example rough, turbid seas).

Human use of coastal and offshore areas is unlikely to change markedly, although it may be altered by changed attitudes towards the affected areas. Thorpe and Foley noted that, while the economic impact of cyclones is typically of most concern initially, cyclones also alter human perceptions of the environment. Their initial studies reveal a coping response typical of most disaster victims, although some locals may have been more affected because of lack of awareness of cyclonic impacts. The coastal area where Winifred crossed is highly regarded for its scenic amenity. The sudden loss of visual amenity caused by defoliation particularly, was therefore potentially more significant than if the cyclone had crossed at other locations.

Thorpe and Foley proposed follow-up studies to evaluate changing perceptions. Of more direct relevance to management, it is proposed to incorporate the potential effects of cyclones into a major study by Griffith University on the crown of thorns phenomena. This should enable comparison of the significance of cyclones and other natural phenomena (crown of thorns starfish, box jellyfish, sharks and the like).

4. RELEVANCE TO THE GREAT BARRIER REEF MARINE PARK

The lessons learned from cyclone Winifred have many implications for management of the Great Barrier Reef Marine Park. The workshop identified the following specific areas as being within the ambit of management.

4.1 Planning

As noted previously (and further in Part B), the short-term effects of cyclones on offshore areas can be severe. Mid to longer term effects may also significantly alter the character of offshore areas. Phenomena such as the destruction of coral, increase in turbidity, and gross changes in reef morphology affect the broad spectrum of human uses of the offshore area. They may also significantly alter the local/regional conservation status of some species and resources.

Such changes alter the relative balance of constraints and opportunities from which zoning plans for Sections of the Marine Park are derived. They cause both temporal disruption and, more importantly, spatial disruption to human use and (potential) enjoyment of the Great Barrier Reef. For example, tourist operations which rely on regular visits to one reef may be displaced if a cyclone severely alters the amenity or character of that reef. Participants observed that the effects of such change would be magnified if the affected reef was an important base for a range of users. Because of this, participants were concerned that increased flexibility may need to be incorporated into the approach of the Authority to planning. It was noted that zoning plans are reviewed every five years.

However, participants felt that some provision should be made for reassessment of zoning plans following natural disasters such as cyclones. One option which could be utilised is an extension of the existing protected areas concept (such as Reef Replenishment Areas) as a short-term measure. A comprehensive planning system should, however, be developed to ensure that the spatial and temporal integrity of plans is not adversely affected.

4.2 Offshore design and development

There was little recorded damage to offshore structures as a result of Winifred, and thus there was little opportunity to assess the adequacy of current design standards and criteria. From data obtained during damage surveys of mainland and island buildings, it was observed that current building standards are appropriate. The damage recorded was within the range expected for a category 3 cyclone, although some unusual effects were recorded due to topographic influences.

The information obtained on processes such as the offshore wind and wave climate during and after Winifred accords reasonably well with historical experience, and with theoretical estimations. It will therefore be useful in future design applications. Participants also agreed that Winifred reinforced the importance of including assessment of cyclonic risk in studies for developments in offshore areas, particularly now that the Authority may need to make provision for the risk of failure of structures by;

- ensuring that development proposals use the best available techniques for assessment of cyclonic impact;

- requiring developments to adopt appropriate design standards and make provision for contingency procedures; and

- requiring developments to provide indemnity in the event of damage or failure occurring.

4.3 Research and monitoring

As noted previously, studies of Winifred generated a large amount of new data on, and a range of insights into, the effects of cyclones. This information is highly important to the management of the Great Barrier Reef system, as the system is comparatively poorly understood at present. Because much of the data presented at the workshop was of a preliminary nature, it is considered worth undertaking follow-up studies to facilitate better understanding of biological processes such as recolonisation and succession, physical processes such as geomorphological change, and socio-economic processes such as readjustment and change in long-term use patterns.

These processes are considered broadly comparable from a management perspective to those associated with other major influences on, and uses of, the reef. For example, such studies could yield useful insights into the effects of ship groundings, coral recovery after crown of thorns starfish predation, and the effects of dredging.

4.4 Education

Thorpe and Foley noted that human response to cyclones involves a succession of stages of coping and readjustment. From experience with previous cyclones in the region, the type of response tends to be closely associated with the level of experience of individuals with the event. Thus, those directly affected endure a more complex process of readjustment, while those outside the immediate area of influence recover more quickly.

Participants agreed that the level of preparedness of individuals, their ability to mitigate risk, and their ability to recover would be improved by education and interpretation programs.

5. ADEQUACY OF THE RESEARCH RESPONSE

The research response to cyclone Winifred was the best achieved in the Great Barrier Reef Region to date in terms of design, range and level of activities undertaken. New insights into the following patterns and processes were obtained;

- ocean-atmosphere interactions;
- oceanographic conditions;
- sediment redistribution;
- impacts on benthic and reef biota;
- effects on island wildlife; and
- effects on human perception and adjustment.

Participants noted that this was achieved largely because of the ready availability of researchers who are competent in these areas. Many were fortuitously working in the area prior to the event and thus mounting a scientific response was logistically much easier than had previously been the case.

However, as implied above, the response was deficient in many respects, particularly in areas such as;

- the use and application of remote sensing techniques to monitor changes in parameters such as turbidity and vegetation cover;
- wave climate data;
- data on offshore economic effects; and
- data on human use of the offshore area in the period after the cyclone crossed the coast.

In addition, it was noted that much of the data obtained was of limited use unless ongoing studies are undertaken.

These deficiencies partly reflect the fragmented nature of the research response. Participants were therefore unanimous in recommending that the response to future cyclone events be both better designed and better co-ordinated, making provision for both short and long-term studies.

A number of proposals were put forward to achieve an improved response to future incidents, including a proposal to have available a fully designed series of studies which can be implemented at short notice. Consistent with this approach, the workshop therefore recommended that:

(a) A meeting of nominated heads of involved institutions be held to determine individual and collective responsibilities and requirements, with a view to developing a co-ordinated response system;

(b) The Great Barrier Reef Marine Park Authority should co-ordinate a multidisciplinary committee to oversee research activities after natural disasters, especially to organise long-term studies; and

(c) A source of funding to enable rapid response to future incidents be identified. This should be considered in the context of the first two recommendations above.

Participants noted that a wide range of expertise already exists in the Great Barrier Reef Region in these fields, particularly at the Centre for Disaster Studies at James Cook University. Such expertise is seen as a major resource in the context of the second recommendation above. Participants also noted that any future response should take advantage of the expertise and capabilities of organisations such as the Department of Defence, the CSIRO and the Natural Disasters Organisation. Although these have responsibilities which may be peripheral to many aspects of the offshore environment, they may be able to contribute complementary expertise and logistical support.

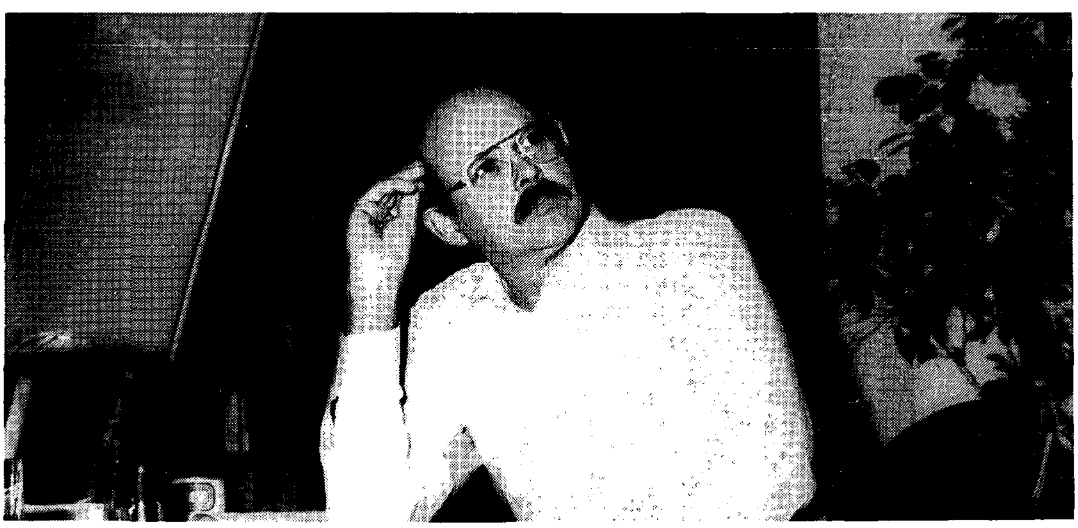
6. CONCLUSION

The workshop reinforced the long-held notion that cyclones are a major influence on the Reef system. A wide range of new data were obtained during and after cyclone Winifred which are of fundamental significance to understanding the reef system.

Unfortunately, in the absence of more comprehensive and longer term studies, the full significance of Winifred to management of the Great Barrier Reef cannot be established. To overcome this, and ensure that the established scientific capability in the Reef Region is properly utilised in future events, a more systematic and comprehensive contingency planning approach has been proposed.

This approach is consistent with the strategies currently being developed by the Marine Park Authority for scientific response to other disasters such as hazardous chemical spills, oil spills, and shipping accidents. Ultimately these approaches should lead to better understanding of resources, uses and resource-use interactions, and a significant improvement in management capability.

Part B



THE SIGNIFICANCE OF CYCLONIC EVENTS TO MANAGEMENT OF THE GREAT BARRIER REEF MARINE PARK

G.G. Kelleher and I.M. Dutton
Great Barrier Reef Marine Park Authority

INTRODUCTION

Cyclones are one of the most significant short-term natural influences shaping the Great Barrier Reef. Since 1984, some 14 cyclones rating category 3 or greater on the Saffir-Simpson scale have affected the north-eastern coast of Queensland.

At the North Queensland Cyclonic Conference held in Townsville in November, 1985, the Queensland Regional Director of the Bureau of Meteorology noted, somewhat prophetically, that it is now some 14 years since a major cyclone has impacted the Queensland eastern seaboard (Falls, 1985).

The Director's prophesy was realised on February 1, 1986, when cyclone Winifred crossed the North Queensland coast south of Innisfail. We will hear later in this workshop that Winifred ranked as one of the most severe since European settlement of the North Queensland region.

From the viewpoint of the Great Barrier Reef Marine Park, Winifred was a very significant event. This point will be expanded later in this paper. However, it is worth noting that the goal of the Great Barrier Reef Marine Park Authority is to provide for the "protection, wise use and enjoyment of the Great Barrier Reef in perpetuity through the development and care of the Great Barrier Reef Marine Park". This goal obligates the Authority to carefully consider the influence of extreme events such as cyclones, relative to the effects of other phenomena (such as human use) and reinforces the importance of the Marine Park concept to long-term conservation of the Great Barrier Reef.

It should also be noted that Winifred was a scientifically significant event. For the first time in the Great Barrier Reef Region detailed scientific information is available, based on before and after surveys of the affected offshore area. Through the auspices of research groups mainly from the James Cook University of North Queensland and the Australian Institute of Marine Science, researchers in North Queensland are well placed to assess the significance of cyclone Winifred.

WINIFRED - A CHANCE EVENT?

While Winifred was the catalyst for much of the scientific research we will hear about later, it should be kept in mind throughout this workshop that Winifred was a chance event both spatially and temporally. As Winifred passed through the Reef tract between 1900 and 2200 hrs, there was a low tide of around 0.82 m at 2100 hrs. The coincidence of seas with a mean wave height in excess of 5 m with the low tide may have maximised physical damage to reefs in the cyclone path.

John Oliver noted in 1974 that the recurrence period for damaging cyclones to a particular locality on the most actively affected parts of the Queensland coast is 20 to 30 years.

On the basis of this information, it is therefore an appropriate question for this workshop to consider later is to what extent can we extrapolate the findings made relative to the impact and severity of Winifred?

CYCLONES AS A SHAPING FORCE

Within days of cyclone Winifred crossing the coast, the Authority arranged for an aerial reconnaissance of coastal and offshore areas. This survey provided little quantitative data. However, it provided useful insights into the extent of influence of the cyclone. For example, the study revealed the extent of influence of coastal flood discharges. Many of the mid-shelf reefs north and south of the cyclone path were noted to be directly influenced by these discharges.

This finding underpins the value to management of studying cyclonic events. As short-term, extreme natural phenomena, they offer a means of investigating ecological patterns and processes which in many cases are subtle or long-term. Another example of direct relevance is the comprehensive research and monitoring program that the Authority has commissioned to assess the effects of sediment exported from the Cape Tribulation to Bloomfield Road on adjacent fringing reefs. Design of the study was complicated by the lack of knowledge of the dynamics of fringing reefs.

A recent extreme influence on these reefs was cyclone Manu. Although that cyclone dissipated offshore, during the period it was positioned offshore from Cooktown, it generated large waves, and was also responsible for the very high rainfall experienced in the Cape Tribulation region. Preliminary surveys on the road project have provided some measure of the extent of these influences. The surveys indicate that such events play a major role in determining the structure, composition and extent of reefal communities. Conversely, Manu has further complicated interpretation of the research and monitoring program results.

MANAGEMENT SIGNIFICANCE

The Authority's goal is to provide for the protection, wise use, appreciation, and enjoyment of the Great Barrier Reef in perpetuity through the development and care of the Great Barrier Reef Marine Park. This involves making provision for sustainable use which will not exceed the repair or replacement capacity of the Reef. Cyclones can have a significant effect on the Reef which, in many cases, can probably be regarded as damaging. It is the Authority's responsibility to ensure that the added impact of human activity does not push the balance of the reef ecosystem beyond its capacity for repair and recovery.

The influence of cyclones such as Manu and Winifred on the offshore Great Barrier Reef typically receives little attention by the community at large. While a cyclone may track many hundreds of kilometres along the Reef tract, most concern is generated when the cyclone turns to cross the coast. Offshore industries such as tourism and fisheries are exceptions to this general trend. They have, in the main, learned to live with such phenomena by the adoption of appropriate design, construction and operation techniques.

However, as we will hear later, based on reports compiled by the Authority, there would appear to be a need for further refinement of such techniques. This workshop should consider how this may be achieved, as the Authority has a strong commitment to ensuring safe, sustainable use of the offshore resources of the Great Barrier Reef.

Other aspects of the management significance of cyclones which merit consideration at this gathering are, socio-economic aspects, including factors such as:

- **The cost of cyclones to offshore industries.** What level of protection against such damage is warranted, and how is it best achieved?

- **The impact of cyclones on offshore activities.** For example, are cyclones a limiting factor on offshore tourism?

- **The perception of cyclones.** For instance, how are cyclones perceived relative to other influences such as crown of thorns starfish outbreaks and the presence of box jellyfish?

It is unlikely that these questions can be adequately addressed at this workshop to provide a more balanced assessment of socio-economic factors. The majority of presentations deal with biophysical factors, largely reflecting the interests of those undertaking the studies. Perhaps future studies could be more comprehensive and better address these aspects.

CONCLUSION

This workshop has two primary objectives;

- to review what was learned from studies of the offshore effects of cyclone Winifred; and

- to review the significance of those findings in the context of our understanding and management of the Great Barrier Reef Region.

Both involve challenging but important questions. This workshop is the first attempt to comprehensively address such questions. Regardless of the limitations of the information available, this workshop will provide an important benchmark for future management reference. It should also provide invaluable guidance on further areas of investigation to assist contingency planning for future cyclonic events in the Great Barrier Reef Region.

THE PERSPECTIVES AND COMMITMENTS OF THE AUSTRALIAN INSTITUTE OF MARINE SCIENCE TO CYCLONE RESEARCH

J.T. Baker and R. Bradbury
Australian Institute of Marine Science

The Australian Institute of Marine Science is committed to research in four general program areas. The first is Coastal Processes and Resources; the second, Reef Studies; the third, Organism-Environment Interaction; and the fourth, Marine Systems and Oceanographic Processes. Cyclones provide an opportunity to study aspects of the environment within all four of these major programs, allowing stresses on the different components to be investigated at a level that could never be achieved by man-made manipulation.

AIMS sees its role as providing scientific investigation and interpretation of phenomena which may occur and in making this information available to management authorities for their use. AIMS is not a management authority. Its skills and its expertise lie in scientific investigation and other organisations are skilled in the various facets of interpretation of data for management purposes. In this respect, AIMS will always be happy to work with the Great Barrier Reef Marine Park Authority (GBRMPA), the James Cook University of North Queensland (JCU), and other agencies to maximise the benefits that can be obtained in immediate field access after cyclonic events.

Despite the close co-operation between AIMS, the University and the Authority, with respect to studies such as the impact of cyclone Winifred, it is possible that we could improve our efficiency for future events by making better known to local authorities and to other agencies - such as the Joint Tropical Trials and Research Establishment (JTTRE) at Cowley Beach - our willingness to be involved in such studies.

One major problem which may exist for future studies is the ability to provide the most rapid forms of transport in the shortest possible intervals to ensure that field operations can be achieved. We should also move to nominate one agency as the co-ordinating agency, and identify a responsible individual therein to initiate the necessary processes to ensure the necessary rapid response.

Cyclone Winifred has led to scientific results which require follow-up investigation after the disturbance and in the event of future cyclonic disturbances. With mangroves, Tom Smith and his colleagues have begun to understand the importance of threshold wind velocities on mangrove systems, but more work is needed to confirm the importance of this phenomenon in explaining the difference in effects on mangroves between cyclones Kathy and Winifred, for example. Studies on biochemical effects by Mark Sandstrom require more detailed analysis in future events; the ability to detect the difference between terrestrial and marine science of organic matter in surface sediments is very important in interpreting the impact of cyclonic events on different terrestrial and marine communities.

Leads have been obtained to indicate the relative abundance of marine algal hydrocarbons at different parts of the reef and suggest algal gradients, but this work again requires follow up studies. With respect to studies of oceanographic conditions, the work of Miles Furnas and Alan Mitchell has shown spectacular differences in light levels and also in nutrient levels in the water column after a cyclone, as compared with normal conditions, and give a clear indication of the reason for plankton blooms as well as a prediction of the length of time for which they may occur.

Other studies have differentiated between the impact of oceanographic conditions, the effects of rainfall, the effects of fresh water and tidal variation on the marine environment, and models have begun to be constructed by Lance Bode and Eric Wolanski.

Dramatic effects on quite massive corals in reefs in the path of cyclone Winifred were observed, and will merit further investigation, particularly in an environment where we are looking forward to the development of offshore structures for tourism in the Great Barrier Reef Region.

It is equally important to study the impact on coral associated organisms from such massive disturbances, and we were fortunate in this case in that the passage of cyclone Winifred was over an area which had been previously surveyed in the crown of thorns starfish survey, conducted under Peter Moran's general supervision.

It is important that AIMS, the Marine Park Authority, James Cook University, and the other agencies do have the organisational facility to respond quickly to massive disturbances such as those represented by cyclones, and it is hoped that all people who are at this seminar would see merit in approaching the Government for provision of special funds which can be accessed over the shortest possible time period to allow us to investigate and obtain a better understanding of the results of the impact of cyclonic disturbances.

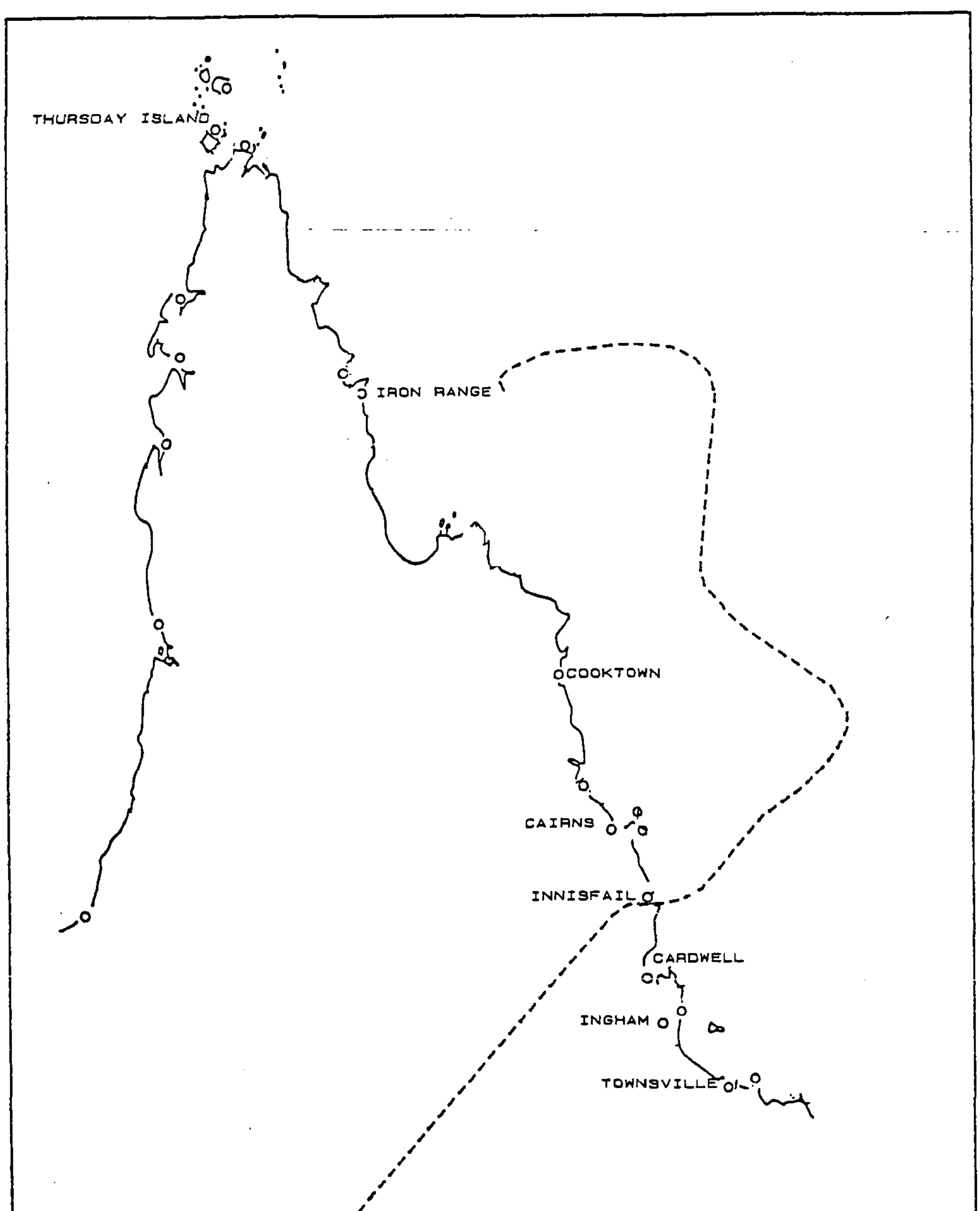
THE METEOROLOGY OF CYCLONE WINIFRED

G. Crane
Bureau of Meteorology

INTRODUCTION

Cyclone Winifred which crossed the North Queensland coast between Cairns and Townsville on February 1, 1986 was the first severe cyclone in 14 years to have a major impact on Australia's east coast. Winifred was therefore a severe test of community preparedness and public understanding of cyclones, as well as of the total warning process. In the hierarchy of severe tropical cyclones, Winifred was of moderate intensity, but relatively large in its area of impact.

Figure 1. Track of cyclone Winifred, from January 27, to February 6, 1986.



TRACK

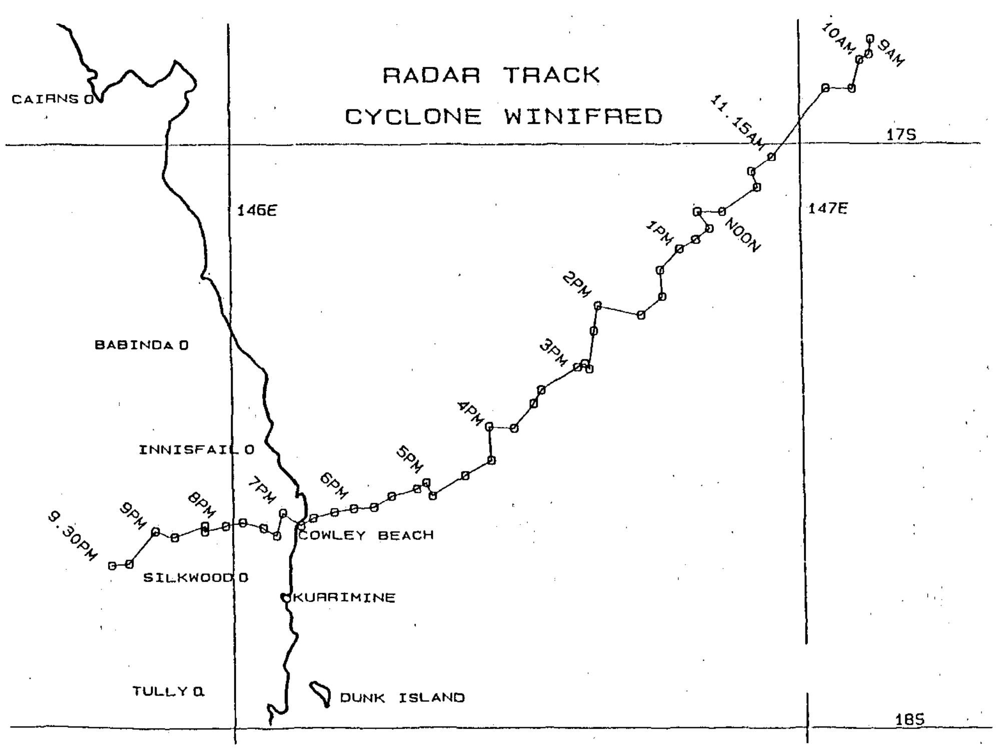
Cyclone Winifred developed from a tropical low, first identified on the afternoon of January 27, approximately 450 km north of Cairns. The low pressure system moved initially in an easterly direction and very slowly intensified. Early on the morning of January 29, the system changed course and commenced moving on a southerly track. By 0400 hrs on January 30 (Day 1), the low had developed into tropical cyclone Winifred with a central pressure of 995 millibars (mb).

Winifred continued to intensify, and underwent two major changes of direction before landfall, firstly from south to south-east on the evening of Day 1, and from south-east to south-west overnight on January 31, (Day 2). The centre temporarily turned from south-west to west-south-west just prior to landfall at 1845 hrs on February 1 (Day 3). Throughout its life prior to landfall, Winifred continued to intensify from its initial pressure of 995 mb to an estimated pressure of 957 mb on landfall. The cyclone weakened as it moved inland but continued to exist as a weakening depression until February 6 (Day 8). The track of the system is shown as Figure 1.

RADAR TRACK

A radar surveillance was maintained by the Cairns Weather Service Office throughout Day 1 and Day 2. Photographs at half-hourly intervals of the plan position indicator (PPI) display which presents a plan view of the echoes from the rain associated with the cyclone were available from 1730 hrs on Day 2 until 1000 hrs on Day 3. From 1000 hrs until 2300 hrs on the Day 3, photographs were available at 15 minute intervals. The main radar features of a tropical cyclone are the eye, which is essentially an echo-free area; and the eye well echo, which surrounds the eye and is approximately circular or slightly elliptical in shape. When discernible features of a cyclone are available on radar, this provides the best means of determining the location of the system and the radar track of Winifred is shown as Figure 2.

Figure 2. Cyclone Winifred: radar track.



The centre of the system was taken to be the geometrical centre of the echo free area within the eye wall. Previous radar observations of tropical cyclones have often shown that the centre appears to move in an irregular fashion with sudden accelerations and deviations from a mean direction of movement, and in this regard Winifred was no exception.

EYE CHARACTERISTICS OF WINIFRED

A partial eye wall echo was discernible on the Cairns radar by 0700 hrs on Day 3 when the centre was located about 185 km from the radar. By 1300 hrs, with the centre 130 km from Cairns, the complete eye was visible and remained so until 2100 hrs, from which time the cyclone began to lose its identifiable radar features.

The radar eye of Winifred was large and mostly elliptical, having a mean diameter of 51 km at 1300 hrs. However, as the cyclone approached the coast, the eye diameter gradually decreased to 49 km by 1700 hrs when the eye well first touched the coast, and to 41 km as the centre of the eye crossed the coast. This decrease in diameter was in agreement with other evidence indicating that the cyclone continued to intensify until landfall at 1845 hrs.

PRESSURE PROFILE

Barograph traces are available from three localities which experienced the cyclone's eye. The centre of the eye passed within 15 km of Innisfail, where a corrected lowest central pressure of 963 mb was recorded. A copy of the trace is shown as Figure 3. The barograph was checked in the week following the cyclone and was found to be reading 2 mb high. At South Johnston, the lowest corrected pressure recorded was 958 mb. A copy of this trace is shown as Figure 4.

Figure 3. Cyclone Winifred: Barograph trace at Innisfail.

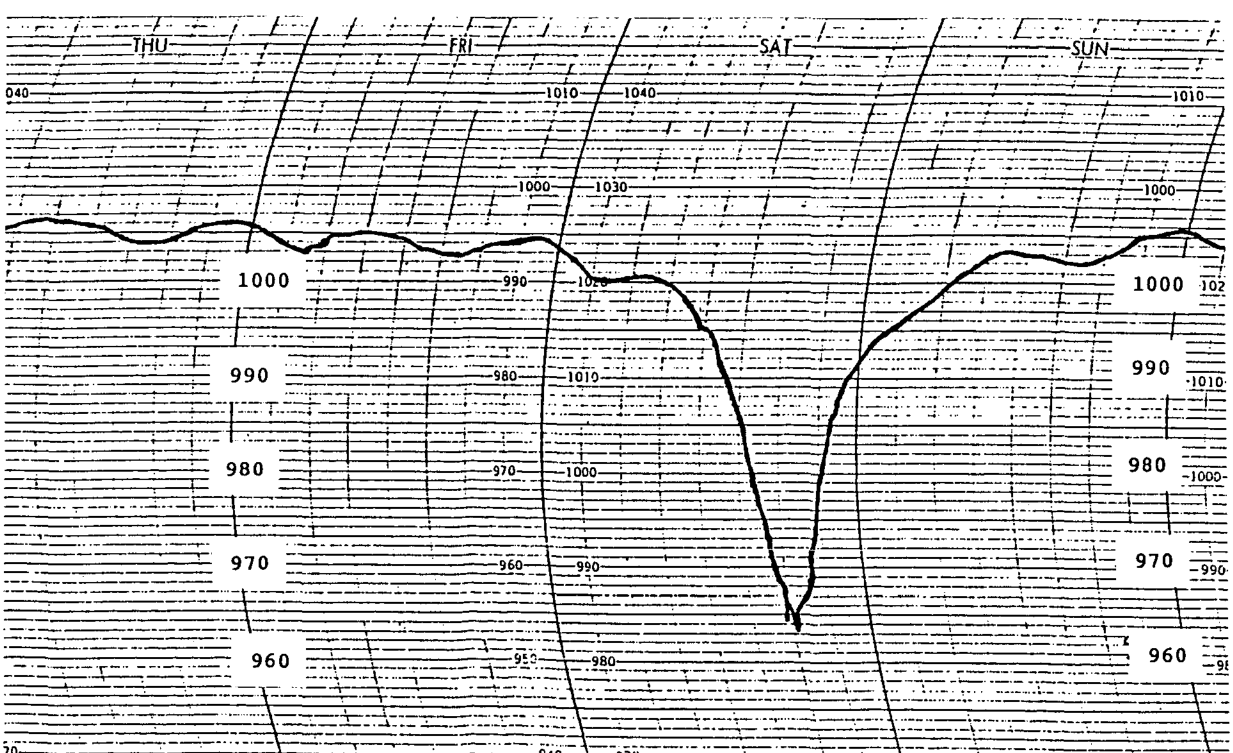
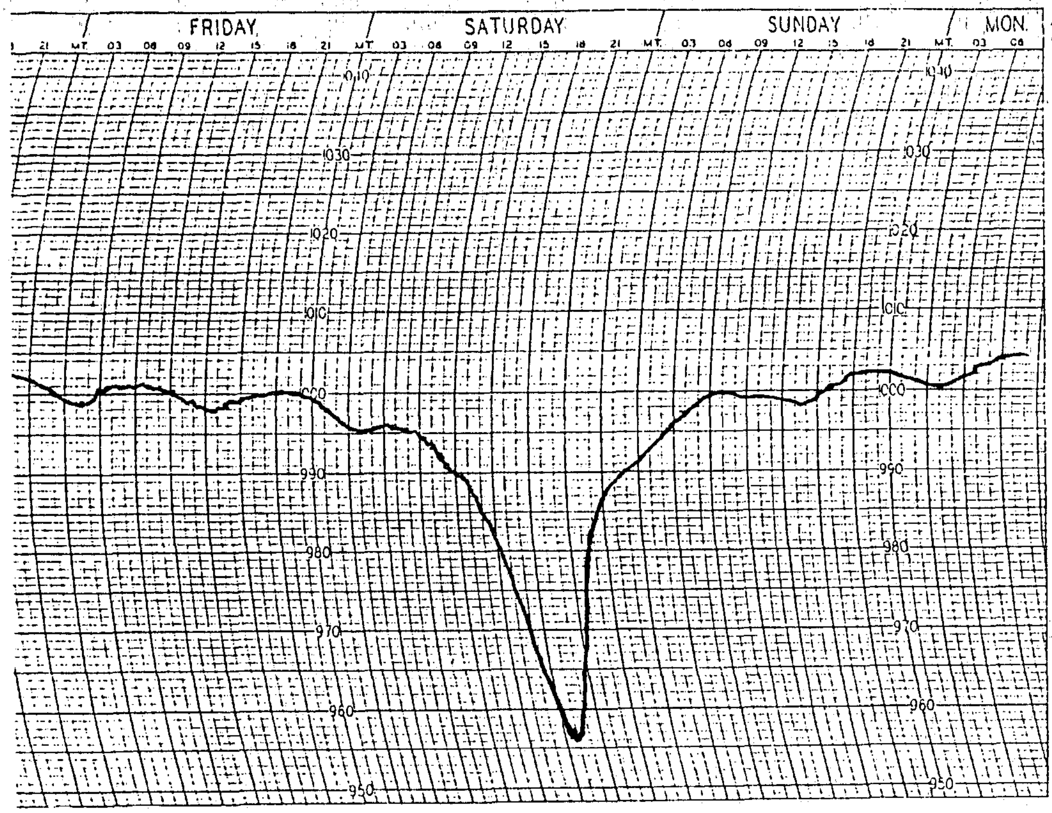
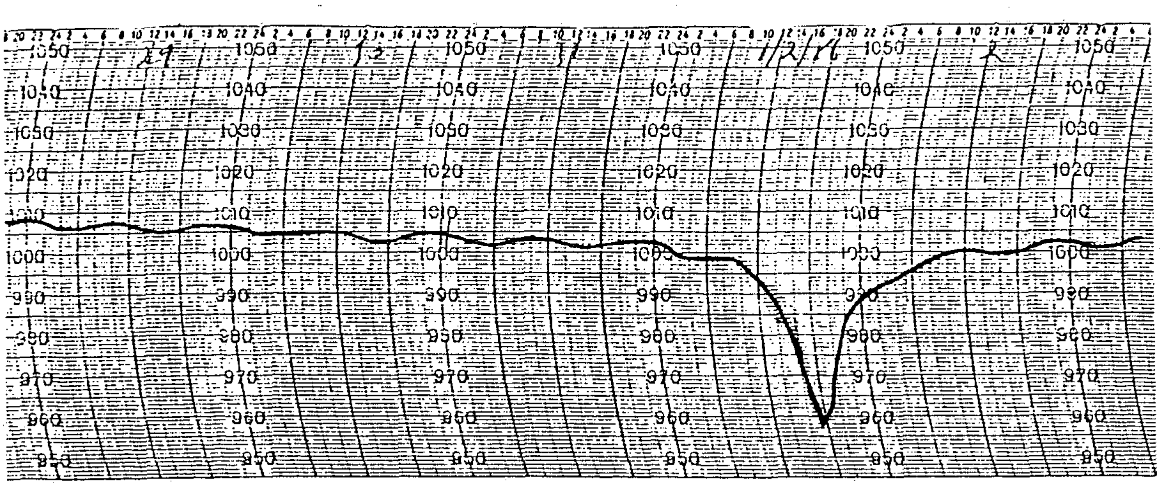


Figure 4. Cyclone Winifred: Barograph trace at South Johnstone.



The centre of the eye passed within a few kilometres of the Joint Tropical Trials and Research Establishment (JTTRE) at Cowley Beach. This station was equipped with a barograph and a synchrotac anemometer. A copy of the barograph trace from Cowley Beach is shown as Figure 5. The lowest central pressure recorded was 958 mb just before 1800 hrs on the Day 3. It is interesting to note that the lowest central pressure occurred approximately one hour before the geometrical centres of the eye was closest to Cowley Beach, suggesting that the pressure centre and the geometrical centre of the eye did not coincide. Pressure values extracted from the trace at Cowley Beach have also been plotted on Figure 6 to allow simultaneous examination of the wind and pressure field at that station.

Figure 5. Cyclone Winifred: Barograph trace at Cowley Beach.

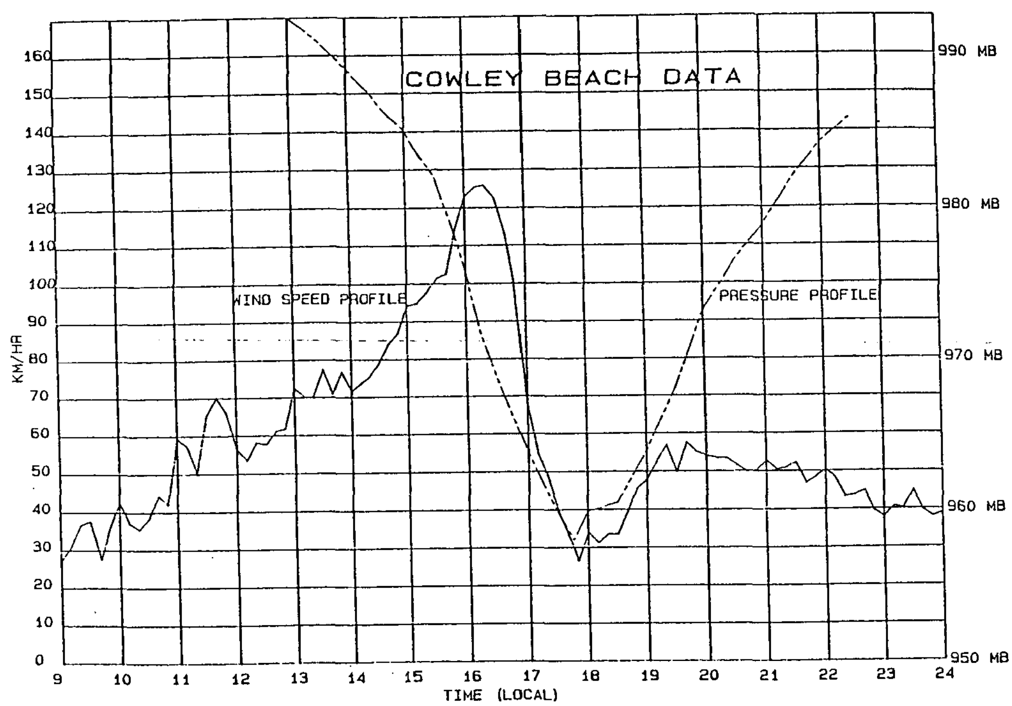


WINDS

The anemometer at Cowley Beach provided 10 minute wind run data in kilometres for each 10 minute period of the day. These data yield the most accurate and detailed description of the windfield associated with Winifred and 10 minute mean winds in kilometres/hour (km/hr) are plotted as Figure 6.

JTTRE have advised that the anemometer does not record 10 minute wind run values between about 21 and 25.5 km; that is, any value of 21 km would be higher, but no higher than 25.5 km. The highest 10 minute wind run recorded was 21 km, which converts to a mean wind of 126 km/hr. Based on the mean wind speed profile shown in Figure 6, it is considered unlikely that this value would have been higher, and 126 km/hr has been accepted as the maximum mean 10 minute wind.

Figure 6. Cyclone Winifred: Wind speed and pressure data - Cowley Beach.



To arrive at an estimate of the peak two to three second gust, it is necessary to apply an approximate gust factor to the mean wind. The major consideration in selecting a gust factor is the surface roughness. The strongest mean winds at Cowley Beach occurred between 1600 hrs and 1630 hrs when the wind direction was south-south-easterly. This indicates that the mean wind was essentially an off water wind and a gust factor of 1.4 would be appropriate. This gives a maximum gust of 176 km/hr.

Remarkably strong winds were recorded as far north as Cairns in the westerly wind regime north of the cyclone centre. The effect of mountainous terrain was clearly evident at Cairns Airport where north-westerly wind gusts to 119 km/hr were recorded while the mean winds were averaging only 45 to 55 km/hr. With such mountainous terrain along the far north tropical coast, large local variations in wind gusts would be expected.

GRADIENT WIND PROFILE

The availability of pressure data from the barograph at Cowley Beach, and the accurate location of the cyclone centre from radar observations enable calculation of the gradient wind profile near the eye. The results of these calculations are shown in Table 1. for the south-south-east wind regime before the passage of the cyclone centre. The gradient wind level is the level at which the wind is not affected by the frictional influence of the earth's surface and is usually about 1 000 m above the surface. In the table, $\triangle$**P** represents the pressure drop during the time that the cyclone approached a distance $\triangle$**R**, **R** is the distance from Cowley Beach, and **Vg** is the gradient wind.

Table 1. Gradient wind profile - cyclone Winifred.

Time (EST)	$\triangle$P (mb)	$\triangle$R (km)	R (km)	Vg (km/hr)
1400 - 1430 hrs	2.0	8.3	56.9	120
1416 - 1445 hrs	2.1	9.3	52.3	111
1430 - 1500 hrs	2.0	8.2	47.6	110
1445 - 1515 hrs	2.6	8.2	43.9	122
1500 - 1530 hrs	3.1	8.7	39.5	123
1515 - 1545 hrs	4.3	9.6	35.2	130
1530 - 1615 hrs	7.4	5.7	26.5	195
1600 - 1630 hrs	7.0	6.1	24.1	175
1615 - 1645 hrs	5.4	7.4	20.4	128
1630 - 1700 hrs	5.0	7.4	16.7	111
1645 - 1715 hrs	4.6	7.2	13.0	96
1700 - 1730 hrs	4.0	6.9	9.5	78

Inspection of the figures in Table 1 indicates that the radius of maximum winds was approximately 27 km. Estimates of the radius of maximum wind using the mean wind speed profile shown in Figure 6, and the speed of the cyclone indicates that this is a realistic assessment. Table 1 also indicates that maximum winds should have been experienced at Cowley Beach at about 1600 hrs ~~which is in close agreement with recorded data.~~

STORM SURGE

When a tropical cyclone crosses or closely approaches a coastline, there is a resultant rise in mean water level above that expected from astronomical tides alone, and this rise in water level is called a storm surge. The abnormal rise in level is caused principally by wind stress on the water surface and the effects of atmospheric pressure reduction. A storm tide is defined as the summation of the storm surge and the astronomical tide. Storm tide is the absolute water level above a stated datum.

The Bureau of Meteorology has responsibility for the production and dissemination of quantitative storm tide warnings to the State Counter Disaster Organisation. Warnings are issued only if the predicted storm tide height exceeds the Highest Astronomical Tide (HAT) at the locations under threat. Qualitative advices of storm threat are included in tropical cyclone warnings which contain landfall or near-landfall predictions.

Throughout Saturday, storm tide gauges at Cairns, Mourilyan, Clump Point, Cardwell and Lucinda were interrogated at regular intervals to monitor tide levels.

Levels at all centres were above predicted astronomical tides throughout the day. With a radius to the region of maximum winds of 27 km at landfall, the peak storm surge would have occurred near the Clump Point to South Mission Beach area. The maximum storm surge recorded at Clump Point was 1.6 m, approximately 0.2 m below the highest astronomical tide. Cardwell recorded a maximum surge of 1.2 m. Using tide heights obtained from interrogation of the gauges and additional data provided by the Beach Protection Authority, plots of actual tides, predicted astronomical tides and storm surge for various centres are shown as Figures 7 to 9.

Figure 7. Cyclone Winifred: Storm tide data - Clump Point.

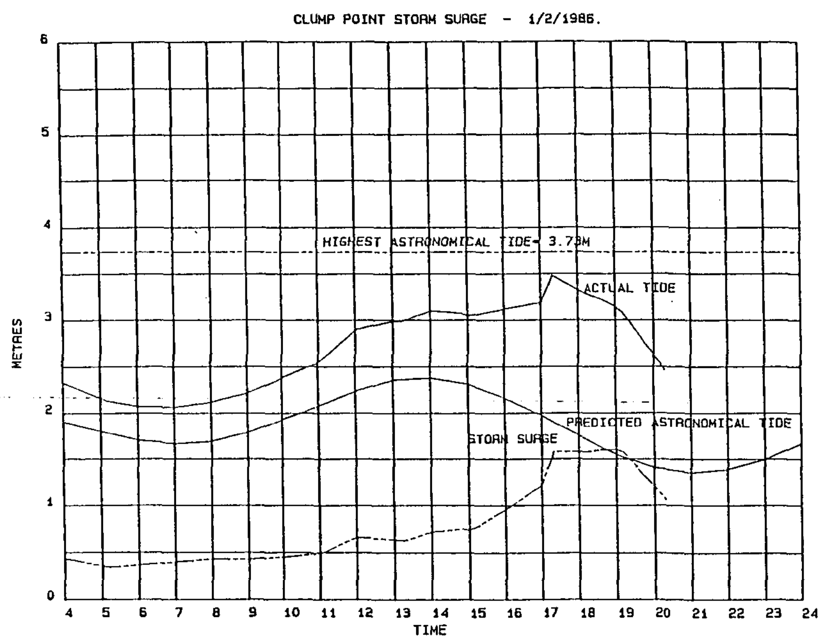


Figure 8. Cyclone Winifred: Storm tide data - Cardwell.

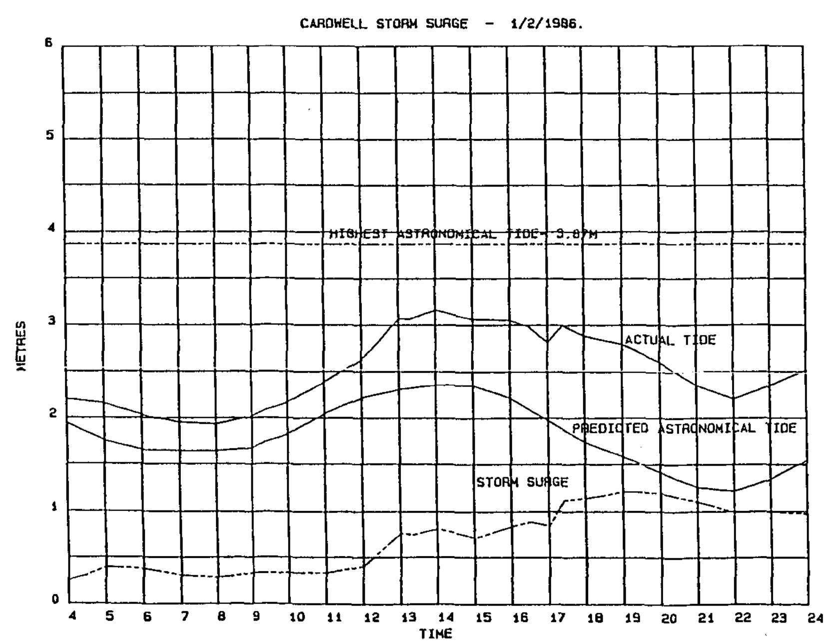
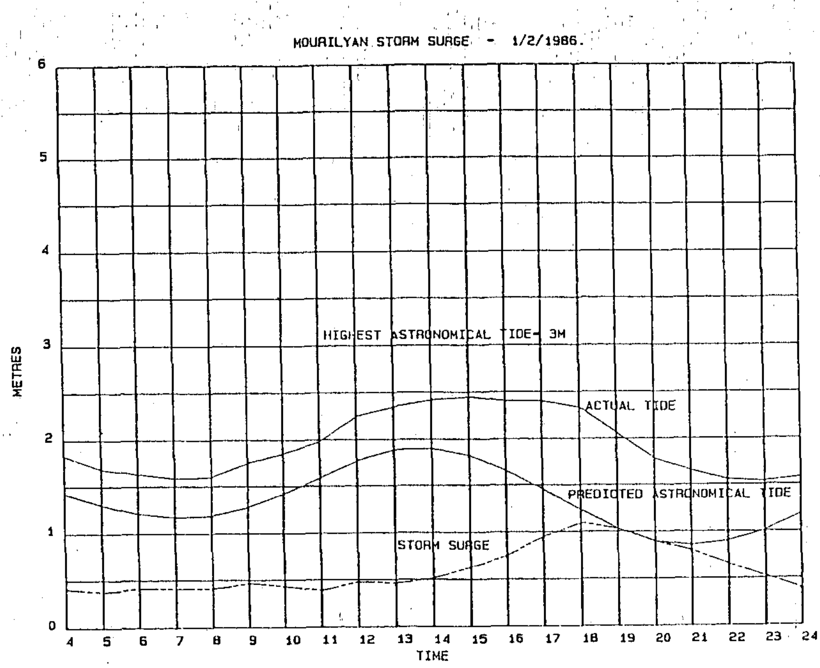


Figure 9. Cyclone Winifred: Storm tide data - Mourilyan.



RAINFALL AND FLOODING

Coastal catchments on the far north tropical coast were generally saturated by heavy rainfall associated with the developing low several days before Winifred made landfall. Between Day 1 and Day 7, totals of over 100 mm were recorded over much of the far north tropical coast and in some inland areas, whilst totals exceeding 500 mm occurred in some coastal areas particularly over the Tully, Herbert and Johnston River catchments. Major flooding resulted in the Tully and Herbert Rivers with river levels approaching record levels.

WIND SPEEDS IN THE GREAT BARRIER REEF REGION FROM CYCLONE WINIFRED AND THEIR EFFECTS ON BUILDINGS

G. R. Walker
James Cook University of North Queensland

G. F. Reardon
James Cook Cyclone Structural Testing Station

SUMMARY

Cyclone Winifred crossed the North Queensland coast near Innisfail late on the afternoon of February 1, 1986. It was the most damaging tropical cyclone to cross the Queensland coast and the most severe to affect the Great Barrier Reef since cyclone Althea in December 1971. Ten minute mean wind speeds exceeding 70 km/hr were probably experienced for a length of over 100 km of the Great Barrier Reef from Flora Passage in the north to Otter Reef in the south, with maxima exceeding 125 km/hr in the vicinity of Hall-Thompson Reef and Geranium Passage. On land wind gusts about 150 km from Cairns to Cardwell with maximum wind gusts estimated to have been of the order of 198 km/hr near the centre of the cyclone. Building damage was mainly restricted to older buildings, with those built since 1980 and incorporating current cyclone resistant construction requirements performing extremely well. The cyclone highlighted the significant influence of topography on the wind characteristics.

INTRODUCTION

Cyclone Winifred formed out of a tropical low, approximately 450 km north of Cairns on January 30, 1986. Late the next evening, after slowly moving roughly parallel to the coast to approximately 250 km east-north-east of Cairns, it turned and moved in a south-westerly direction across the Great Barrier Reef (Figure 1). The centre of the cyclone would have passed almost directly over Wardle, Cayley, and Feather Reefs before crossing the coast just south of Mourilyan Harbour in the vicinity of Double Point, late in the afternoon of February 1. Just prior to crossing the coast, Winifred changed course to a more easterly direction.

At the time it crossed the coast, the Bureau of Meteorology has estimated that the central pressure of Winifred was 957 mb and that it had been continuing to intensify until it crossed the coast. It was travelling at approximately 15 km/hr and had an unusually large eye of the order of 50 km in diameter, which extended from north of Flying Fish Point south to the vicinity of Clump Point when it crossed the coast (Figure 2). After the centre crossed the coast, the eye decreased in size and does not appear to have persisted more than 60 km inland.

Figure 1. Approximate track of cyclone Winifred (based on information supplied by the Bureau of Meteorology).

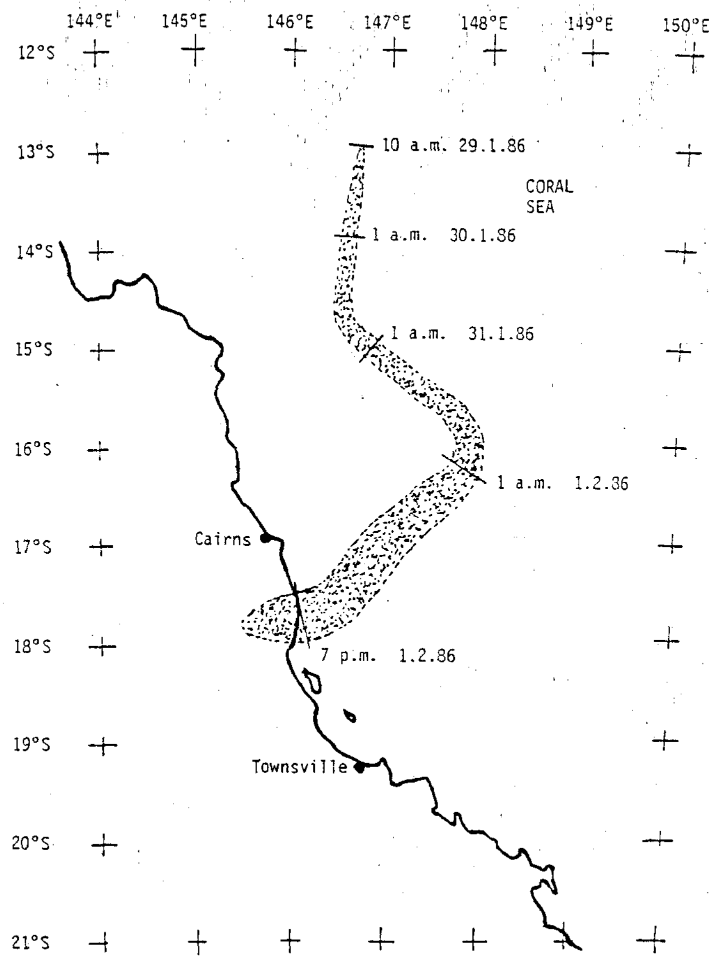
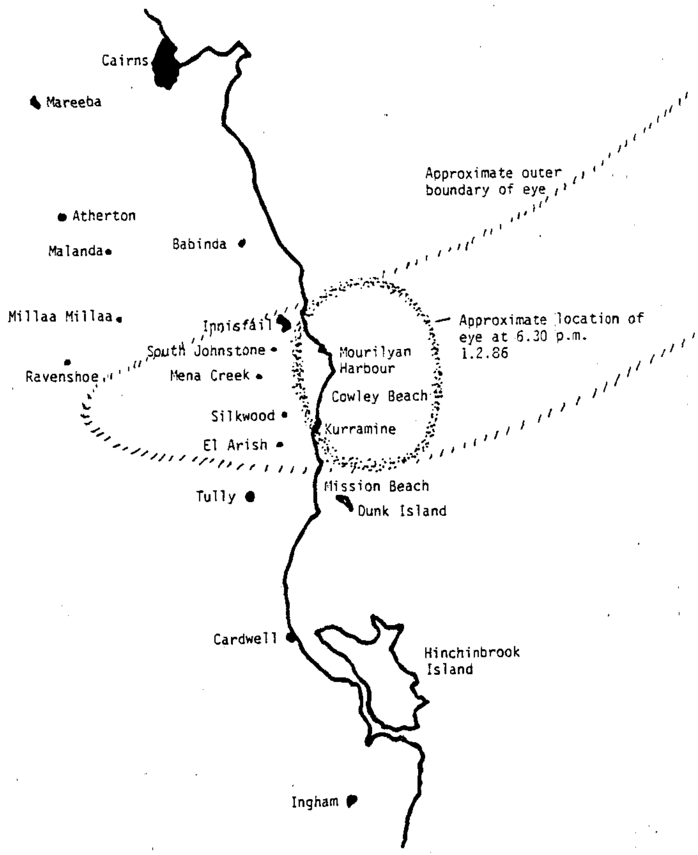


Figure 2. Location of cyclone Winifred as it crossed the coast.



On the international five point Saffir-Simpson scale (Table 1), Winifred would be classed as a severe cyclone of intensity 3, as far as central pressure and wind speeds are concerned. Cyclone Althea, which damaged Townsville in 1971, was also an intensity 3 cyclone. Cyclone Tracy which devastated Darwin in 1974, fell into intensity class 4. Catastrophic cyclones of intensity 5 are very rare. The most well known example of a cyclone of this intensity is hurricane Camille which hit the southern coast of the United States in 1969.

Table 1. Intensity scale of tropical cyclones.
(after Simpson and Riehl, 1981)

Magnitude	Saffir-Simpson scale	Central pressure (mb)	Maximum Wind Gusts (knots)	Maximum Wind Gusts (km/hr)	Maximum Storm Surge (m)
Mild	1	>990	40-60	72-108	0-1
Moderate	2	970-985	70-90	126-162	1.5-2.5
Severe	3	950-965	100-120	180-216	3-4
Very Severe	4	930-945	130-150	234-270	4.5-5.5
Catastrophic	5	<925	160-180	288-324	6-7

It must be emphasised that the relationships shown in Table 1 are only approximate, and that many cyclones do not fit this pattern. For instance, cyclone Tracy was only an intensity 3 in terms of central pressure and storm surge although an intensity 4 in terms of wind. Winifred itself was only intensity 2 in terms of storm-surge, although intensity 3 in other respects.

Records of cyclones in the region over the past 120 years suggest that an average of about two intensity 3 cyclones cross the Great Barrier Reef per decade. Only two intensity 4 cyclones are believed to have crossed the Great Barrier Reef this century; the Innisfail and Mackay cyclones of 1918, which occurred within two months of each other. If reports are correct, the 1899 Bathurst Bay cyclone, also known as cyclone Mahina (Holthouse, 1971) (which still holds the record for the greatest number of lives lost in an Australian cyclone since European settlement) was an intensity 5 cyclone.

WIND SPEEDS

Recorded data

The nearest anemometer operated by the Bureau of Meteorology was at Cairns, which was too far from the centre of Winifred to be of much use in determining wind speeds in its vicinity. Fortunately however, the Department of Defence has an anemometer at Cowley Beach, which was within the eye of the cyclone as it crossed the coast and just south of its centre. This anemometer remained operational throughout the passage of the cyclone and provided a very good record of the wind speed characteristics of Winifred as it crossed the coast.

The Cowley Beach instrument is a synchrotac anemometer and gives ten minute mean wind speeds for successive ten minute periods throughout the day, as well as the instantaneous wind direction every ten minutes. Plots of the recorded wind speeds and wind directions are shown in Figure 3.

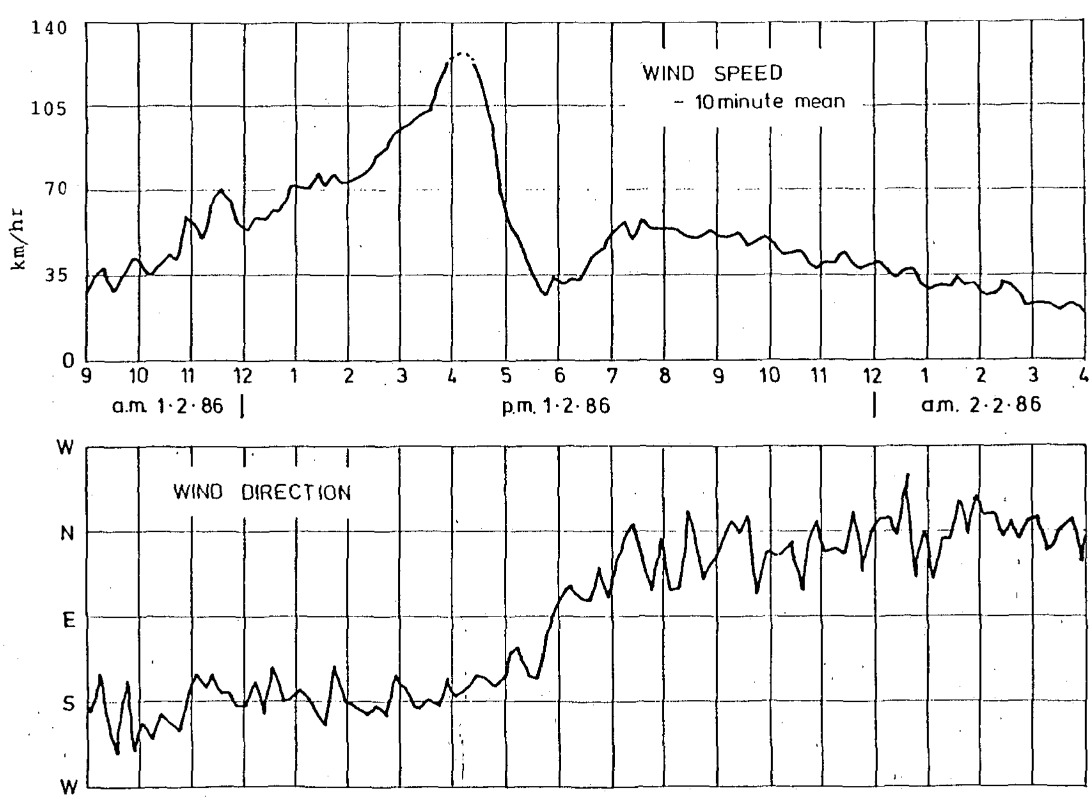
The anemometer is located approximately 18 m inland from the beach, at a height of 10 m, in flat open terrain. From south through east to north-east, the directions from which the wind was primarily blowing during the passage of Winifred, the fetch is over the sea. From the other directions, with the exception of south-south-west to west the fetch is over at least 5 km of flat scrub covered land.

Unfortunately, due to limitations in the instrument's recording system, there is a question mark regarding the reliability of the three maximum wind speed readings. However, comparison with past records of wind speeds near the centre of tropical cyclones suggests that the indicated values are close to the actual values that occurred. On the basis of this record it appears reasonable to assign a maximum ten minute mean wind speed at 10 m height of 126 km/hr at Cowley Beach.

The sharp drop in wind speed after 1630 hrs indicates the arrival of the eye. The much lower wind speeds recorded following the passage of the eye suggest that by this time with the centre of the eye 20 to 30 km inland and the leading edge of the eye 40 to 50 km inland Winifred had weakened considerably in intensity.

The jagged nature of the wind direction plot reflects the effect of turbulence on instantaneous wind direction. The smoothed curve through the points is a more realistic description of the 10 minute mean wind directions. The change in direction from the south as the cyclone approached through east to north-north-east as the cyclone passed over is consistent with the location of the anemometer being slightly south of the path of the centre of the eye.

Figure 3. Wind records obtained at Cowley Beach during cyclone Winifred.



Wind speeds over the sea

The wind speed at a particular location and time during a tropical cyclone is a function of the central pressure, the radius of maximum winds, the forward speed of the cyclone, location relative to the centre of the eye, the surface terrain, the height above the surface, latitude, topography and other meteorological factors. A number of mathematical models of varying complexity have been developed to describe the wind field. These are generally only strictly applicable over the sea because of the complications arising from the weakening in intensity once cyclones cross the coast, and the influence of topography.

These models are mostly semi-empirical in nature, and based on fitting observed data from previous tropical cyclones. The wind speed is normally made up of two components - one arising from the rotating nature of the cyclone and the other from the forward speed of the cyclone. Examples of these are to be found in Graham and Nunn (1959), Martin (1954), Atkinson and Holliday (1975), Gomes and Vickery (1976), Tryggvason (1979) and Georgiou, Davenport and Vickery (1983).

For determining the pattern of maximum 10 minute mean wind speeds over the sea at a height of 10 m the following formula can be shown to be a reasonable approximation in the southern hemisphere:

Along the track of the centre of the eye:

$$V = C\sqrt{p_c - 1010} \cdot \left(\frac{R}{r}\right)^k$$

To the left of the track of the eye:

$$V = C\sqrt{p_c - 1010} \cdot \left(\frac{R}{r}\right)^k + 0.5\ V_s$$

To the right of the track of the eye:

$$V = C\sqrt{p_c - 1010} \cdot \left(\frac{R}{r}\right)^k - 0.5\ V_s$$

where; **V** = maximum ten minute mean wind speed (km/hr)

$\mathbf{p_c}$ = central pressure (mb)

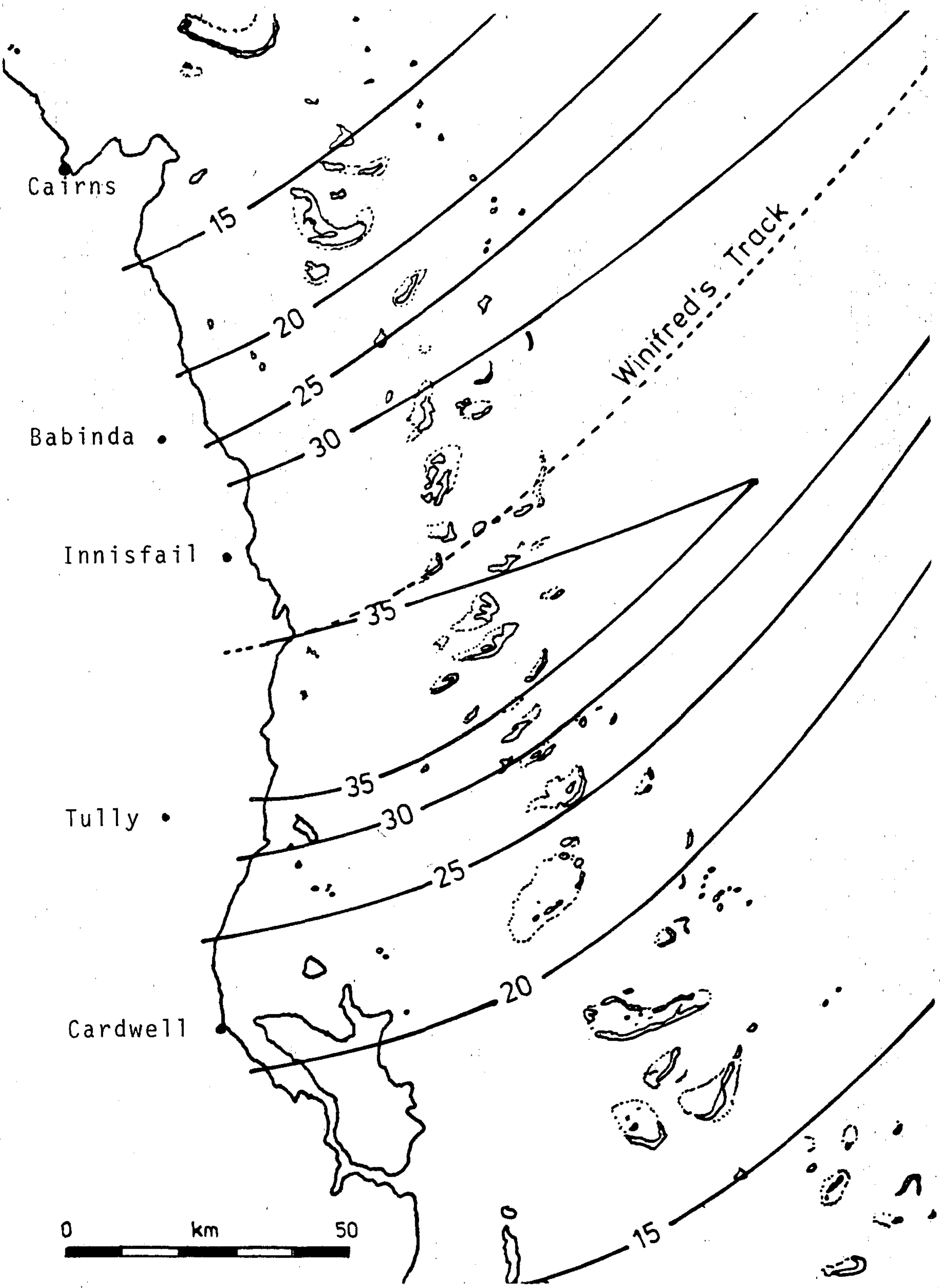
R = radius of maximum winds (km)

$\mathbf{V_s}$ = forward speed of cyclone (km/hr)

C,**k** = constants obtained by fitting to cyclone data.

For Winifred, **C** and **k** can be determined from the Cowley Beach record since it was close enough to the centre of the cyclone for the maximum recorded wind speed of 126 km/hr to be assumed as the maximum wind speed along the track, when the central pressure was 957 mb, and for the plot of increasing wind speed as Winifred approached to be used to evaluate **k**, assuming a steady forward speed of approach of the order of 45 km/hr. This gives us a reasonable approximation **C** = 4.8 and **k** = 0.67. Using these constants in the above formulae in conjunction with information on central pressure along the track of Winifred approached the coast supplied by the Bureau of Meteorology the wind field map shown in Figure 4 was obtained.

Figure 4. Map of estimated maximum 10 minute mean windspeeds over the Great Barrier Reef area during Winifred.



It will be seen that the reefs experiencing the highest 10 minute mean wind speeds were probably Hall-Thompson Reef, Adelaide Reef, and Ellison Reef. The maximum wind speeds would have been of the order of 133 km/hr from east to north-east. Reefs from Gibson and Hedley Reefs in the north to Farquaharson Reef in the south probably experienced 10 minute mean wind speeds in excess of 110 km/hr, and those from Flora Passage in the north to Otter Reef in the south probably experienced ten minute mean wind speeds in excess of 70 km/hr. For those to the north of the eye the maximum wind speeds were probably from the south-west to west, while those near the centre of the eye probably experienced maximum wind speeds from the south-east prior to the eye, followed by strong winds from the north-west following the passage of the eye.

While 10 minute mean wind speeds are the most relevant in relation to the sea state and effects related to this, wind effects on structures are more a function of the maximum wind gust speeds. In Australia for instance, wind loading criteria for building design are related to the maximum expected three second gust speeds. The relationship between three second wind gust speed at the same location depends on the turbulent characteristics of the wind (Cook, 1985). For steady wind over the sea these change with wind speed due to the increasing roughness of the sea as wind speeds increase. For the range of interest a ratio of 1:4 is commonly assumed, but studies by Melbourne (1984) of wind records obtained in Hong Kong during typhoons suggest that this may underestimate the gust speeds in the region of maximum winds with ratios between 1:4 and 1:5 being relatively common. The increased turbulence giving rise to these higher values may be due to wind shears within the cyclone. For wind off the land, significantly higher gust ratios could be obtained, particularly, if the terrain is very rough.

Wind speeds over land

Over the land, it is the wind gusts that generally cause the problems rather than the mean wind speeds. The discussion in this section will therefore be in terms of the maximum three second gust speed at 10 m height over flat open terrain, this being the standard reference for expressing wind speeds by the Bureau of Meteorology and for building design standards.

If the land is flat and featureless, it could be assumed that the wind field over the land would be very similar to the wind field over the sea until the eye crossed the coast and would then contract as the cyclone weakened as it moved inland. Even if no information was available on the weakening after crossing the coast, this approach would be expected to at least give a good indication of wind speeds near the coast before the cyclone weakened.

However, rarely is the land flat and featureless, and cyclone Winifred highlighted how misleading this approach can be when the topography is very rough as it is in North Queensland. Figure 5 shows the pattern of estimated maximum gust speeds based on a gust ratio of 1:1.45 just prior to Winifred crossing the coast. Apart from near the centre of the cyclone, the pattern of building damage and the measured wind speeds at Cairns indicate this is a poor representation of the actual wind gust speeds that occurred in Winifred. The reason for this is believed to be the very rugged topography of the area.

Figure 5. Postulated maximum gust speeds as Winifred approached land. Based on cyclone windspeed model over the sea.

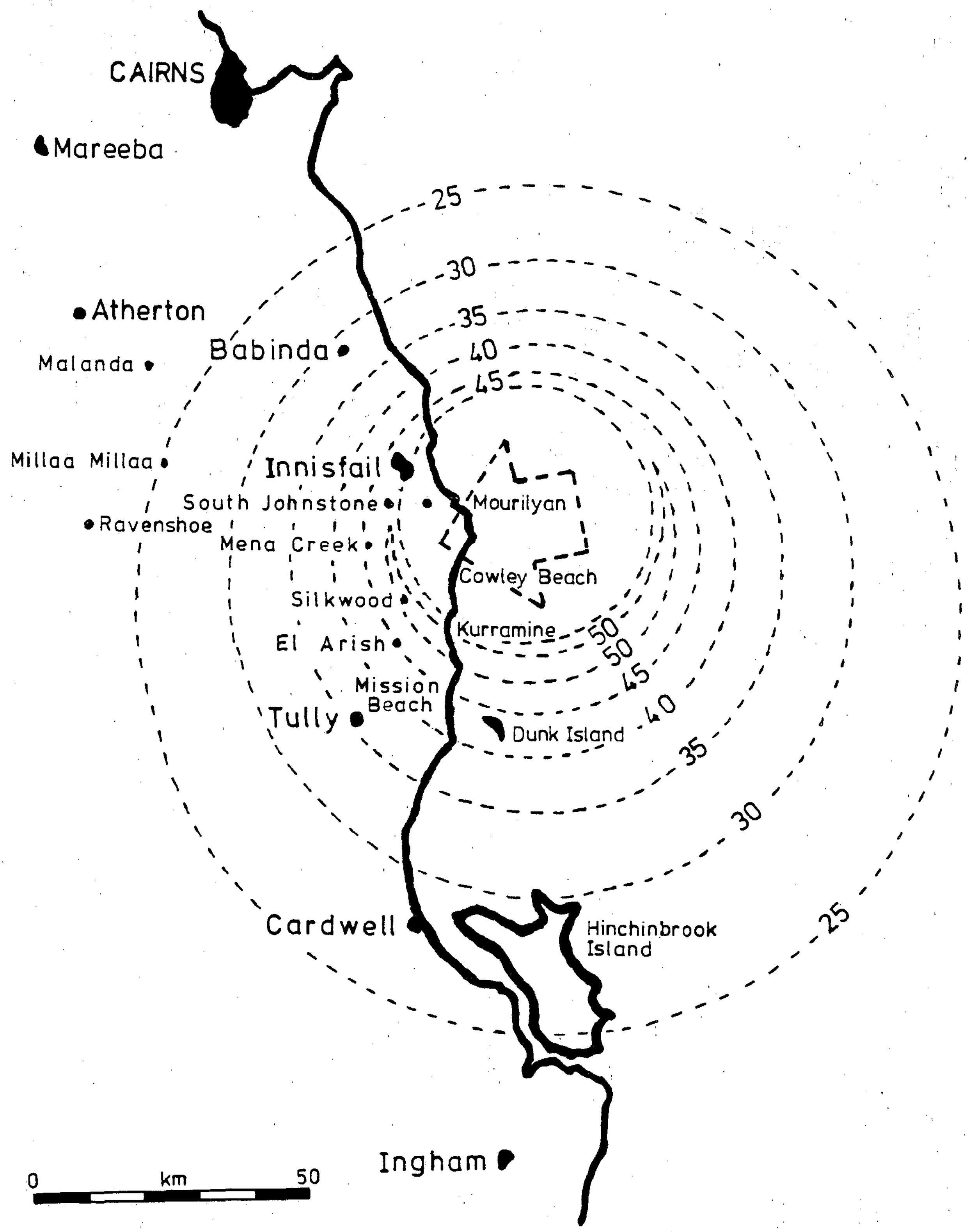
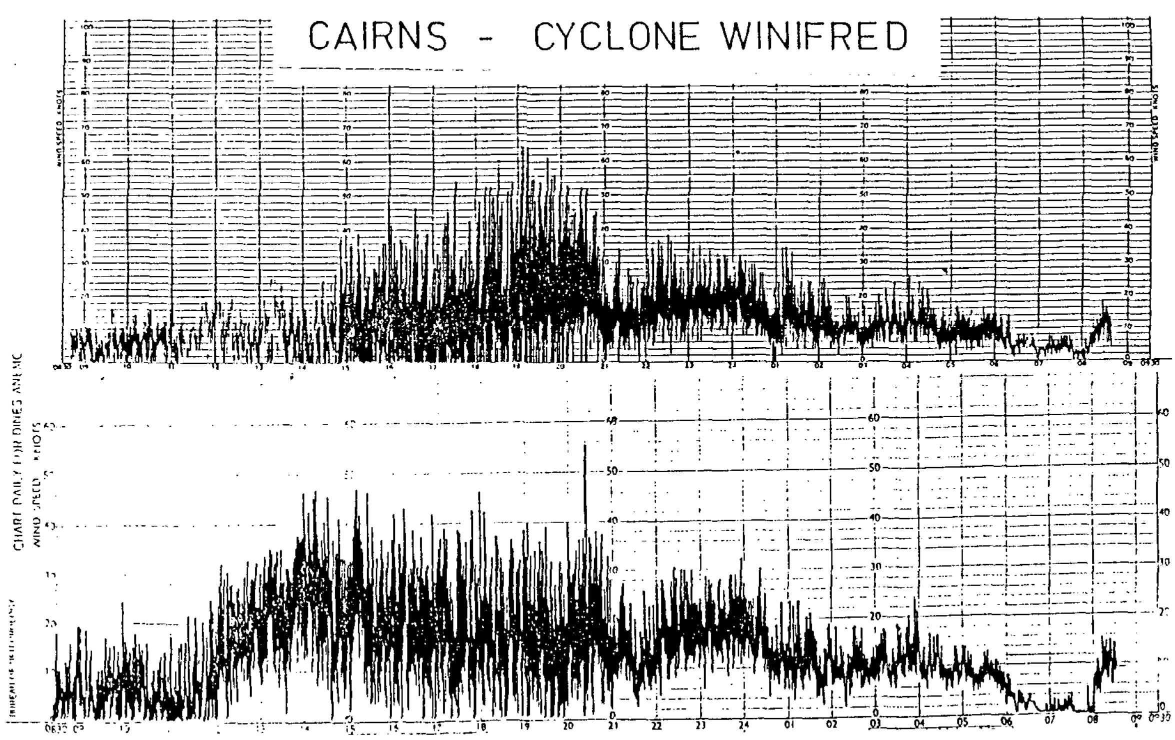


Figure 5 suggests that the highest wind speeds would have been experienced in the Kurrimine Beach to Bingil Bay area, with maximum wind gusts between 180 and 198 km/hr occurring, which is consistent with observed wind damage. Away from this area, however, there are many inconsistencies. For instance, Figure 5 suggests that Tully and Innisfail should have experienced similar wind speeds with maximum wind gusts between 160 and 180 km/hr, and Babinda and Cardwell much less with maximum wind gusts of the order of 125 and 108 km/hr respectively. Yet observations of wind damage suggest that while the wind speeds in Babinda and Tully were much less than in Innisfail, the wind speeds in Babinda were similar to those experienced in Innisfail, and the wind speeds in Cardwell were less than would have been expected from this analysis.

The overall impression was that on land, wind speeds to the north were greater than those to the south, contradicting the normally held view of wind fields in tropical cyclones. Topographical sheltering in the case of Tully and Cardwell, and topographical funnelling in the case of Babinda were probably major factors in these anomalies. High levels of turbulence generated by wind flow over the rugged topography, causing high gust speeds even if mean wind speeds were relatively low, was probably a significant factor in amplifying the gust speeds in general to the north of Winifred's path.

Figure 6. Records of windspeed obtained at Cairns Airport during cyclone Winifred.



The wind records obtained at Cairns by the Bureau of Meteorology highlight the effect the topography can have on wind speed patterns. The Bureau operates two anemometers at Cairns Airport approximately one kilometre apart. Figure 6 shows the two wind speed records obtained from these during Winifred. The most striking feature is the difference between the two records. One measured a mazimum wind gust of 119 km/hr at about 1915 hrs, and the other a maximum of 105 km/hr over an hour later; the shape of the two records is quite different.

The difference is believed to be due to the close proximity of a large hill with the highest reading being obtained from the anemometer closest to the hill due to local acceleration of wind around the edge of the hill. It will also be noticed that both the maxima are well above the expected value based on Figure 5. However, closer inspection will show that the mean wind speeds were at all times less than 54 km/hr which is consistent with Figure 4 and indicates that it is high gust ratios in excess of 1:2 due to very high levels of turbulence that are the principal reasons for the high maximum gust speeds, again highlighting the significance of topographic effect on wind speeds on land.

BUILDING DAMAGE

Building damage was in general much less than originally reported in the media. It is estimated that less than five percent of the buildings in the area affected by Winifred suffered significant damage, and that damage was less in proportional terms than occurred in Townsville during cyclone Althea. The latter is attributed to wind speeds in the major communities affected probably being slightly lower, the much better performance of houses built in accordance with the new cyclone resistant building regulations, and improvements in the fastening of roof cladding on older buildings undertaken since cyclone Althea.

Although larger buildings have been structurally engineered to resist wind loads for many years, it was not until after the devastation of Darwin by cyclone Tracy that a serious attempt was made to provide the same level of structural safety to housing and other small buildings (Walker, 1980). In Queensland, the resulting changes to building construction were implemented progressively as they were developed, and formalised in 1982 with the adoption of the Home Building Code Queensland as Appendix 4 of the Queensland Building By-Laws (Queensland Government, 1981). In achieving these changes Australia has pioneered the development of wind resistant housing construction and provided a model for the rest of the world (Walker and Eaton, 1983). Cyclone Winifred provided the first real test of these new requirements.

The current building regulations in cyclone-prone areas of Queensland are designed to minimise damage in the event of an intensity 4 cyclone. Consequently, as Winifred was only an intensity 3 event, all buildings constructed to the new building standards should have survived undamaged. With minor exceptions, this proved to be the case, with damage to buildings less than five years old being almost wholly restricted to failure of attachments such as guttering and awnings (Reardon, Walker and Jancauskas, 1986). Nowhere was the improved performance of housing better demonstrated than at Kurrimine Beach, which was probably subjected to the maximum winds in the cyclone. There a group of older housing suffered relatively serious damage with 20 to 30 percent of buildings having significant structural damage, but a group of recent houses and an hotel in identical conditions of exposure, suffered only minor non-structural damage.

The most severe damage to a relatively new building observed was to a house at Coquette Point near Innisfail. This house, which was less than five years old and appeared to have been built with regard to the new regulations, suffered severe roof and wall damage to half of the building.

The mode of failure was probably a failure on the windward wall leading to internal pressurisation, causing the roof to blow off followed by wall collapse. The reason for failure was probably because of topographical factors not appreciated at the time of its design. Coquette Point is a ridge about 70 m high, with the house located on the crest.

Recent overseas research (Cook, 1985) has shown that high accelerations of the wind can occur in such locations which, in the case of Coquette Point, could have resulted in wind speeds at the crest being of the order of 70 percent higher than they would have been over the surrounding flat land resulting in wind forces two and a half to three times what the wind forces would have been on houses on the flat land. This highlights another influence of topography which has generally not been fully recognised in the construction of houses in very exposed locations such as the tops of hills and ridges and the edges of escarpments. Most of the severe damage to older houses occurred in similar locations.

Two other significant structural failures of relatively new buildings occurred. One was the failure of a roof on a house due to uplift of the roof structure originating, it appeared, at the outside edge of the verandah due to smaller fasteners being used than were specified. The other was the removal of a large section of roof cladding from a school assembly building in Cairns. The building was less than two years old and wind speeds in Cairns were very low relative to design wind speeds. In this case, the use of a cladding system which did not appear to have been tested for cyclonic conditions (Experimental Building Station, 1977), and poor installation were apparently to blame. Both these cases highlight the importance of quality control in the construction of buildings in cyclone-prone areas.

Another potential problem brought to notice by Winifred was corrosion of metal components. The failure of a carport approximately 15 years old due to corrosion of the steel supporting columns was observed at Kurrimine Beach, and several reports were received of failure of roof cladding fasteners less than five years old, due to corrosion.

The poor performance of guttering and awnings has already been mentioned. Apart from the cost of replacement, the potential debris hazard of these elements in a more serious blow is a matter of some concern. Entry of water around windows, doors and air conditioning units was a significant cause of contents damage in buildings otherwise undamaged. It is not realised by many people that the waterproofing requirements for these elements do not generally cover cyclonic conditions.

In respect of older buildings, it was noticeable that when roof cladding was removed by the wind, in many cases it took the battens or purlins with it. This was generally as a result of the attachment of the cladding having been upgraded in recent years without any improvements being made to the remainder of the roof structure. Overall, the improvement in cladding fastening probably did reduce the total amount of damage by lifting the damage threshold, but the batten failures indicated the limitations in damage reduction that can be expected from this form of upgrading on its own.

A final lesson to be learned from Winifred in respect of building performance is the danger of using older buildings as places of refuge during tropical cyclones. School buildings are often designated for this purpose. For instance, prior to Winifred making landfall, the residents of Kurrimine Beach were evacuated to Silkwood State School in case a major storm surge had accompanied the cyclone. The construction of this school pre-dated the current cyclone requirements and, like many of its contemporary buildings, it suffered some roof damage. At Innisfail High School a major structural failure occurred in a building of similar vintage. In an intensity 4 cyclone, failures of these older buildings could be expected to be much more widespread posing a grave danger to persons using them as refuges.

CONCLUSIONS

On the five point Saffir-Simpson scale, Winifred would be classed an as intensity 3 cyclone, similar to cyclone Althea, and much less intense than cyclone Tracy.

Maximum 10 minute mean wind speeds at 10 m height over the sea were probably a little over 125 km/hr. Approximately 50 km of the Reef would have experienced mean wind speeds in excess of 110 km/hr, and over 100 km would have experienced mean wind speeds in excess of 70 km/hr.

On land, maximum wind gusts of the order of 180 to 200 km/hr, in terms of three second gusts at 10 m height in flat open terrain, were probably experienced in the Kurrimine Beach to Bingil Bay area. The rugged topography of the area appears to have had a major influence on the wind pattern over the land.

Buildings built to the current building standards had an excellent overall performance. Where failures of these buildings did occur they appear to have been associated with severe topographical effects not fully appreciated in their design or to lapses in quality control in their construction. The poor performance of guttering and awnings, and evidence of corrosion problems were of some concern.

Although improvements in the attachment of cladding appeared to have led to some reduction in the overall damage to older buildings the latter still suffered significant damage from inherent structural inadequacies. Unless such buildings are fully upgraded to the current standards their use as places of public refuge during tropical cyclones should be avoided.

ACKNOWLEDGEMENTS

The co-operation of the Bureau of Meteorology and the Department of Defence in providing the meteorological information used in this paper is gratefully appreciated.

REFERENCES

Atkinson, G.D.and Holliday, C.R. 1975. Tropical cyclone minimum sea level pressure - maximum sustained wind relationships for the western North Pacific. Bulletin of the American Meteorological Society, 56,2.

Cook, N.J. 1985. The Designer's Guide to Wind Loading of Building Structures, Part 1. Butterworths, London.

Experimental Building Station. 1977. Guidelines for cyclone product testing and evaluation. Technical Report 440, Experimental Building Station, Sydney.

Georgiou, P.N., Davenport, A.G., and Vickery, B.J. 1983. Design wind speeds in regions dominated by tropical cyclones. Journal of Wind Engineering and Industrial Aerodynamics, 13,139-152.

Gomes, L. and Vickery, B.J. 1976. Tropical cyclone gust speeds along the northern Australian coast. Civil Engineering Transactions, Institution of Engineers Australia, CE18,2,40-48.

Graham, H.E. and Nunn, D.E. 1959. Meteorological considerations pertinent to standard project hurricanes, Atlantic and Gulf Coasts of the United States. National Hurricane Research Project Report, number 33, U.S. Department of Commerce, Washington.

Holthouse, H. 1971. Cyclone. Rigby, Adelaide.

Martin, G.S. 1974. Probability distributions for hurricane wind gust speeds on the Australian coast. Proceedings, Conference on Applications of Probability Theory to Structural Design, Institution of Engineers Australia, Melbourne.

Melbourne, W.H. 1984. Design wind data for Hong Kong and surrounding coastline. Proceedings of the Third International Conference of Tall Buildings, Hong Kong.

Queensland Government 1981. Home building Code Queensland. Appendix 4, Standard Building By-Laws 1975, Queensland Government Printer, Brisbane.

Reardon, G.F., Walker, G.R. and Jancauskas, E.D. 1986. The effects of cyclone Winifred on buildings. Technical Report Number 26, James Cook Cyclone Structural Testing Station, Townsville.

Simpson, R.H. and Riehl, H. 1981. The Hurricane and its Impact. Lousisiana State University Press, Baton Rouge.

Tryggvason, B.V. 1979. Computer simulation of tropical cyclone wind effects for Australia. Wind Engineering Report Number 2/79, Department of Civil and Systems Engineering, James Cook University of North Queensland, Townsville.

Walker, G.R. 1980. A review of the impact of cyclone Tracy on Australian building codes and practice. Civil Engineering Transactions, Institution of Engineers, Australia, CE22, 2, 100-107.

Walker, G.R. and Eaton K.J. 1978. Application of wind engineering to low rise housing. Journal of Wind Engineering and Industrial Aerodynamics, 14, 91-102.

OCEANOGRAPHIC CONDITIONS ON THE NORTH QUEENSLAND SHELF AFTER PASSAGE OF CYCLONE WINIFRED

M. Furnas and A. Mitchell
Australian Institute of Marine Science

An intensive oceanographic survey (February 4 to 9, 1986), was carried out in shelf waters surrounding the Winifred storm track shortly after its passage through the GBR. Extensive mixing caused by energetic cyclonic winds (greater than 200 km/hr), coupled with rainfall and river runoff produced dramatic changes in shelf waters. These changes included:

Greatly increased water turbidity

While GBR and lagoon waters are normally quite clear (from 0.5 to 5 percent of surface light can be measured at the bottom of the mid and outer shelf: a depth of 60 to 80 m), greatly increased turbidity reduced measurable light penetration to less than 5 m inshore, and less than 35 m on the outer shelf. Sources of this suspended material included river plumes from the Herbert, Tully, Murray and Johnstone Rivers, resuspended lagoon and reef sediments, and blooming plankton.

Reductions in shelf water salinity

Near-surface waters across the shelf were measurably diluted with freshwater. Measured salinities ranged from 10 parts per thousand (ppt) near the mouth of the Tully river to about 35 ppt. Observable plume structures in the lagoon ranged from less than 1 m, to several metres thick. By February 6, plumes from the Johnstone and Murray Rivers were considerably reduced and trapped near the shoreline.

Dissolved nutrient levels increase

Inter-reef and lagoon waters are normally characterized by low and uniform distributions of dissolved nutrients, particularly of nitrogen. Following Winifred, concentrations of inorganic nitrogen species - ammonium and nitrate - were readily detectable and often quite high (greater than 1 um). Sources of the nutrients added to shelf waters include river runoff, pore water from resuspended sediments and rainfall. With time, nutrient levels declined, particularly in a surface waters as plankton blooms developed.

Plankton blooms in inter-reef and lagoon waters

Following the injection of large amounts of nutrients into shelf waters, a pronounced phytoplankton bloom developed in the cyclone track area within two days. Chlorophyll concentrations were frequently five to 10 times higher than normally measured in mid-shelf waters and surface blooms extended to the shelf break. Blooming populations were dominated by net phytoplankton (greater than 10 uM). Despite high water column turbidity, primary production rates measured on the mid and outer shelf were also five to 10 times higher than normal.

No obvious effects of cyclone Winifred were observed in waters off Townsville, at stations occupied on February 10 and 15. Despite the dramatic shifts observed in shelf waters after the passage of Winifred, these changes are short-lived and are likely to have few direct effects upon the Great Barrier Reef. Indirect effects remain to be established.

SOME COMPARISONS BETWEEN OBSERVED AND MODELLED OCEANOGRAPHIC RESPONSE TO TROPICAL CYCLONE WINIFRED

L. Bode
James Cook University of North Queensland

E. Wolanski
Australian Institute of Marine Science

Between January 5 and April 3, 1986, an array of oceanographic instruments was deployed at four locations in a cross-shelf line from Hinchinbrook Island to Britomart Reef. This array was designed to measure current profiles, coastal water elevation, water salinity and temperature. The centre of the eye of cyclone Winifred crossed the coast roughly 80 km to the north of the array. The currents were primarily northward and barotropic before the storm landed. Thereafter, the currents reversed rapidly, and the vertical shear became considerable in coastal waters. A pool of fresh water was found offshore, probably generated by rainfall, followed several days later by freshwater plumes inshore.

A two-dimensional numerical hydrodynamic model of the shelf water response to the passage of cyclone Winifred has been constructed. This uses available meteorological data on the storm (central pressure, speed and direction of its track, radius of maximum winds) and known astronomical tidal elevations as its forcing, to allow a combined storm/tidal simulation to be performed. Results from the model are the fields of sea surface elevation and depth-averaged currents, with subtraction of the tidal fields producing the net storm-induced response. The time series obtained from the model are compared with the observations at the four instrumented locations.

SEDIMENT REDISTRIBUTION ON THE GREAT BARRIER REEF SHELF BY CYCLONE WINIFRED

D.P. Johnson, R.M. Carter, M.K. Gagan, J.E. Dye, and D.L. Carr,
James Cook University of North Queensland

Severe tropical cyclone Winifred traversed the Great Barrier Reef shelf between Cairns and Tully on February 1, 1986. Pre-cyclone studies had outlined the shelf bedforms and terrigenous-carbonate facies patterns between the coast and the inner shelf of the reef tract. Re-surveys commencing four days after Winifred demonstrated the following data:

Large areas of the inner shelf were bathed in surficial muddy river plumes, some of which reached 30 km seaward to the inner edge of the Reef tract. Suspended material was present throughout the shelf water column. In mid-shelf areas (water depths greater than 20 m), the particulate content increased towards the seafloor, to a maximum concentration of 6 milligrams per litre.

A seaward-thinning mud drape, generally 10 to 100 mm thick, was present on the inner and middle shelf. Commonly, a normally graded, medium sand to silt layer occurred at the base of this mud drape. Elsewhere, particularly on the middle shelf, a medium to coarse shelly or quartzose lag was present, either at the surface or under a mud drape a few millimetres thick.

Off-reef and shoreward transport and deposition of skeletal debris and carbonate fines took place from the inner edge of the Reef tract during and after the cyclone.

The mud drape incorporates material from three sources, in varying proportions across the shelf. The sources are; new river influx, resuspended bottom sediment and, material derived from nearby reefs.

Longitudinal bedforms were widespread on the middle shelf at water depths of 28 to 35 m, and form a furrowed substrate of linear convex ridges, approximately 1 m high and 40 to 150 m wide, separated by narrow V-shaped depressions. The ridges consist of terrigenous and biogenic muddy sand and gravel, overlying a mottled pleistocene clay.

Northward facing 1.2 to 2 m wavelength megaripples occur in the furrows between the ridges; megaripples also occur in extensive fields outside zones of ridges.

Well-sorted quartzose/bioclastic sand less than 10 mm thick occurs on top of some convex ridges, probably representing sand ribbons developed in sympathy with the underlying ridge topography.

It is inferred that storm-waves associated with the passage of cyclone Winifred caused widespread unmixing of bottom sediments. On the middle shelf, long-shelf transport of bedload sand ribbons and megaripples was effected by powerful northward-flowing bottom currents. Wind-forced downwelling may have resulted in offshore water flow along the seafloor, depositing the graded bed. As the storm decayed, a widespread mud drape began to accumulate. Bioturbation had started within a few days, was well advanced after three months, and is expected to homogenise the thin sedimentary units produced by the cyclone.

BIOCHEMICAL EFFECTS OF CYCLONE WINIFRED

M.W. Sandstrom
Australian Institute of Marine Science

The distribution of terrestrial organic material in inner and middle shelf and Reef lagoon sediments off the coast near Innisfail immediately following cyclone Winifred was determined to examine the influence of cyclonic river discharge across the shelf. Capillary gas chromatography of aliphatic hydrocarbons and carbon isotope analysis of bulk organic matter was used to identify terrestrial and marine sources or organic matter in surface sediments. Lagoon sediments from Feather, Gilbey and Potter Reefs were characterized by hydrocarbon distributions indicative of algal sources; terrestrial hydrocarbons were not present above detectable levels. Carbon-13 analysis also indicated an absence of terrestrial higher plant material, with values between 19 and 15 ppt for all reef samples. The abundance of algal hydrocarbons and organic material increased from outer to middle shelf reefs, suggesting there may have been a gradient in productivity across the shelf.

Terrestrial hydrocarbons derived from higher plants were abundant in sediments close to the mouth of the Johnstone River, and decreased to low levels in middle shelf sediments. Carbon-13 analysis also indicated a gradient in terrestrial organic material across the shelf, with values decreasing from 26 ppt near the Johnstone River, to 14 ppt, typical of reef derived organic material, in sediments near the reefs.

Cyclonic river discharge of terrestrial organic material, and presumably other nutrients, seems to have been confined to the inner and middle shelf, despite the fact that river discharge was greater than average daily wet season discharge. Hence the phytoplankton bloom that occurred in middle and outer shelf reefs and inter-reef lagoon waters after the cyclone must have been the result of nutrient input from alternative sources. Resuspension of bottom sediments by cyclonic winds and release of pore water nutrients into the water column is suggested as an important source of nutrients for phytoplankton productivity in the reef waters, rather than river discharge.

SOME PRELIMINARY OBSERVATIONS FROM A SURVEY OF THE SOFT SEDIMENT BIOTA OF THE INNER AND MIDDLE SHELF OF THE GREAT BARRIER REEF FOLLOWING CYCLONE WINIFRED

A. Birtles
James Cook University of North Queensland

Documentation of the effects of cyclones, hurricanes or even storms on the macrobenthos of soft sediment areas is extremely limited. Accounts have often come from higher latitudes than the Great Barrier Reef and have rarely included numerical data. Even the most relevant have been restricted to shallow water (Stephenson et al., 1974 and 1977) and usually estuarine conditions (Andrews, 1973; Reish, 1965). They have primarily demonstrated the biological effects of drastic salinity reductions, and few have examined the effects of siltation in any detail. There is even less information on the physical effects of water movement.

The passage of cyclone Winifred over the Great Barrier Reef lagoon near Innisfail early in February 1986, provided an opportunity to document some of the effects on the macrobenthos of the area.

A survey was undertaken between February 9 and 12, using the methods indicated in Birtles and Arnold (1983), and Arnold and Birtles (1985). Ninety samples were obtained from two transects running between the coast and the inner line of reefs. The most intensive sampling, using grabs, sledges, trawls and Scuba diving, was concentrated at six sites along the southern transect, east of Mourilyan Harbour. Sites and samples are shown in Figure 1.

The infaunal samples have not been examined, but initial observations of the sledge and trawl samples shows strong evidence of zoning of the epifaunal assemblages across the shelf in a comparable manner to that demonstrated in other parts of the Reef (Arnold and Birtles, 1985). A diverse epifaunal component had survived to the time of sampling, although heavy siltation was apparent across the shelf with particularly marked effects in the shallower stations. Pronounced sand waves were seen at 33 m; their structure and attendant biota was examined.

Some preliminary observations will be presented from the survey and compared with information available from other areas.

ACKNOWLEDGEMENTS

This study was funded by GBRMPA, and both the Authority and MSTGS are gratefully acknowledged. I. Dight, S. Lemmens, A. Mckenna and B. Nesbitt volunteered their kind assistance in the field, and thanks are also due to the JCU Geology Department and the crew of the MV James Kirby for facilitating this survey at necessarily short notice. Thanks are due to P. Arnold in particular for much advice and innumerable valuable discussions.

Figure 1. Post-cyclone Winifred sampling. Stations 1404 to 1457, 9/2/86 to 12/2/86.

Transect 1: Mourilyan Harbour 078° to the south end of Feather Reef: 14 nautical miles.

Station numbers	G1	G76	G75	G74	G73	G72	G71	G70
Distance from North Head, Mourilyan Harbour (nautical miles)	1	2.1	3.0	5.3	6.7	8.6	11.4	13.5
Depth (m)	13	17	22	27	29	31	38	45
Frame-supported van Veen grabs (three replicate 76 mm diameter cores from each)	1404	1405	1406	1407	1408	1409	1410	1411
Smith McIntyre grabs (.06 sq m)	1440 1441	1444 1445	1448 1449	1423 1424		1434 1435	1428 1429	
Modified Ocklemann sledges (.65 m gape)	1442 1443	1446 1447	1450 1451	1422 1425 1426 1427		1436 1437 1438 1439	1430 1431 1432 1433	
Six fathom "Yankee" otter trawls	1457	1456		1455		1454	1452	
Scuba dives						1453		

Transect II: Ella Bay 072° to north of Arthur Patches; 17 nautical miles.

Station numbers.	V11	V9	V7	G63	G64	G65	G66	G67	G68	G69
Distance offshore (nautical miles)	1	2.5	4.0	5.7	7.7	9.6	11.4	13.4	15.2	16.8
Depth (m)	3	12	22	25	27	29	31	38	41	35
Frame-supported van Veen grabs (three replicate 76 mm diameter cores each)	1421	1420	1419	1418	1417	1416	1412	1413	1414	1415

REFERENCES

Arnold, P.W. and R.A. Birtles. 1985. Zoning the Central Section of the Great Barrier Reef Marine Park for the conservation and management of the soft sediment areas of the continental shelf. Report to the Great Barrier Reef Marine Park Authority, Townsville.

Andrews, J.D. 1973. Effects of tropical Storm Agnes on epifaunal invertebrates in Virginial estuaries. Chesapeake Science. 14: 223-234.

Birtles, R.A. and P.W. Arnold. 1983. Between the reefs: some patterns of soft substrate epibenthos on the central Great Barrier Reef shelf. Proceedings of the Inaugural Great Barrier Reef Conference, Townsville. 159-163.

Boesch, D.F. R.J. Diaz and R.W. Virnstein. 1976. Effects of Tropical Storm Agnes on Soft-bottom Macrobenthic Communities of the James and York Estuaries and the Lower Chesapeake Bay. Chesapeake Science. 17: 246-259.

Stephenson, W., S.D. Cook and Y.I. Raphael. 1977. The effect of a major flood on the macrobenthos of Bramble Bay Queensland. Memoranda of the Queensland Museum. 18(1):95-119.

Stephenson, W., W.T. Williams and S.D. Cook. 1974. The benthic fauna of soft bottoms, Southern Moreton Bay. Memoranda of the Queensland Museum. 17: 73-123

Stone, A.N. and D.J. Reish, 1965. The effects of freshwater runoff on a population of estuarine polychaetous annelids. California Academy of Science. 64: 111-119.

CYCLONE WINIFRED - OBSERVATONS ON SOME ECOLOGICAL AND GEOMORPHOLOGICAL EFFECTS

T.J. Done, P.J. Moran and L. de Vantier
Australian Institute of Marine Science

Cyclones constitute short lived and extreme physical disturbances to coral reefs, affecting all levels of ecosystem organization, from individual organisms, through local populations and communities, to the physical structure of reefs. Cyclone Winifred passed through an area in which the majority of reefs had already been heavily impacted by the crown of thorns starfish in the previous one to five years. This coincidence of two severe disturbances; one physical and one biological; raises fundamental questions about the role of disturbance in the coral reef ecosystem. Are their effects additive; are long-term changes in the character of the reef likely to result; and are such changes outside the 'normal' range of variability of the reef through time? These questions are far from being answered at this time.

The first step towards addressing such fundamental questions is the assessment of the immediate impact of the disturbances through field observations. Line and photo transects had previously been established on several reefs affected by the cyclone. They have subsequently been re-surveyed, allowing the extent of very localized changes to be assessed. While details varied from place to place, in all cases the already low cover of live coral was reduced even further, and there was at least superficial damage to the Reef framework.

The broader extent and nature of damage was assessed using both manta board and scuba observations on 10 reefs over a 160 km section of the Great Barrier Reef, centered on the cyclone path. The surveys were conducted within six weeks of the cyclone. Damage was classified as follows:

- breakage of coral;
- dislodgement of coral;
- scouring of soft benthos;
- peeling of surface matrix;
- slab removal of reef matrix;
- bulk transport of sediment; and,
- sand blasting of corals.

The latter four forms of damage constitute superficial changes to gross reef morphology which were nevertheless very conspicuous underwater. However, there was no damage to the structure of the reefs, such as tossing up of large reef blocks onto the reef flat, which was visible in aerial surveys conducted three days after the cyclone. Since many reefs in the area are littered with such storm-tossed blocks, Winifred appears to have been of lesser consequence in this regard than earlier cyclones.

The nature of benthic and superficial structural damage and its location on individual reefs varied in a systematic pattern in relation to predicted wind direction and reef position. On a series of reefs within 30 km of the path of the cyclone, reefs farthest from the coast appeared to receive more structural damage than those near to shore, but even the worst affected reefs appeared to have little damage on their landward sides. On reefs 60 to 75 km to the north of the path, damage was greatest on the landward side, which would have been open to cyclonic waves with a westerly component. On reefs 120 to 140 km to the south, there was significant damage to live and dead coral on parts of reefs exposed to cyclonic waves, which in this sector, would have had a strong easterly component.

The extent of changes to the benthic communities in the initial years following the cyclone will be followed by continued monitoring of the permanent study sites. The interpretation of these results in terms of the fundamental questions raised above will be based on a very incomplete understanding of reef structure and function. However the focus which these disturbances bring to the study of reef ecosystems can only improve our understanding of those systems.

THE EFFECTS OF CYCLONE WINIFRED ON CORALS AT GREEN ISLAND REEF

V.J. Harriott and D.A. Fisk
James Cook University of North Queensland

ABSTRACT

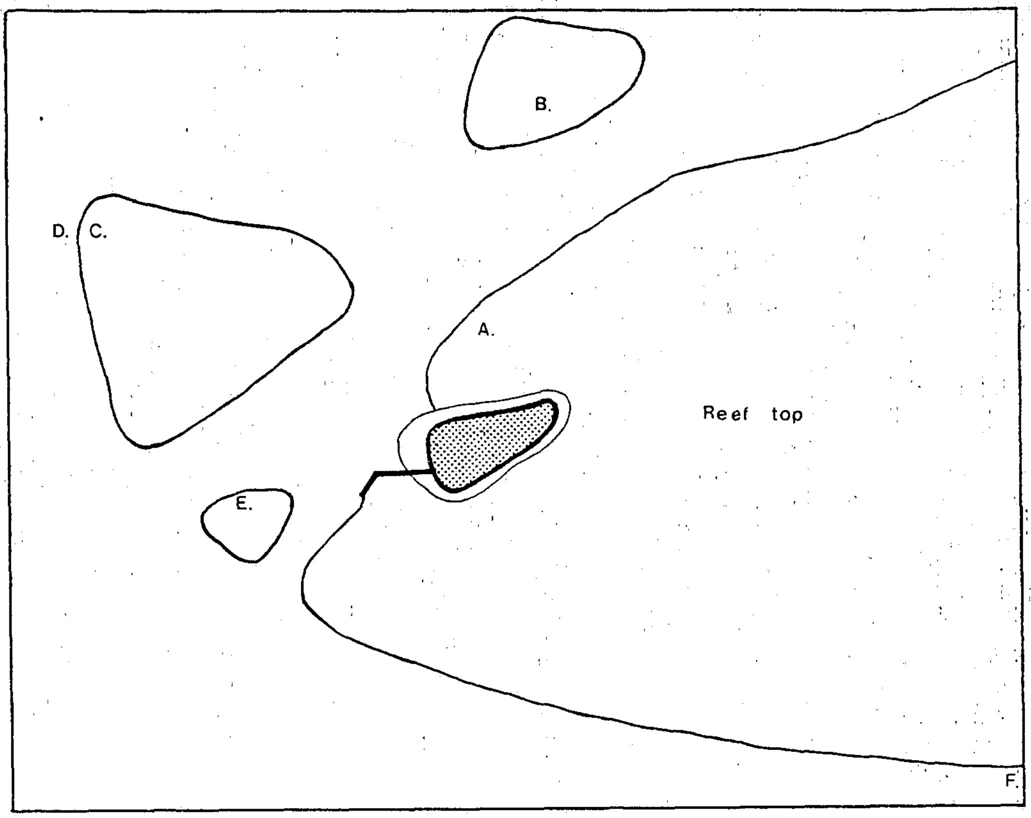
Cyclone Winifred passed close to Green Island in February, 1986, producing strong winds and heavy seas from the north-west. Cover of hard and soft corals was measured at six sites on Green Island reef before and after the cyclone. There was no significant change in soft coral cover as a result of the cyclone, and the cover of hard coral was reduced significantly at only one of the six sites. There was little evidence of a large-scale collapse of dead standing coral as had been predicted for reefs damaged by the crown of thorns starfish (Acanthaster planci). It is suggested that damage to the coral community was small because the hard corals are in an early successional stage following severe damage by A. planci, and small corals are less likely to be damaged by water movement than those with a higher profile.

INTRODUCTION

The eye of cyclone Winifred, with wind gusts up to 180 km/hr near the centre, passed approximately 80 km south of Green Island on February 1, 1986. Green Island lies approximately 20 km off the coast from Cairns. It is a well known tourist destination on the Great Barrier Reef and is the site where, for the first time, the large populations of crown of thorns starfish were recorded in the 1960's. The Reef was again affected by large populations of the starfish in 1979/80, and is the site for a study of regeneration of hard corals after predation by Acanthaster. The data-set for the regeneration study provides a baseline against which changes caused by cyclone Winifred can be measured.

While there is a large body of work on the effects of cyclones (or hurricanes) on coral reefs (including Woodley et al., 1981; Porter et al., 1981; Stoddart, 1969; Endean, 1976; Rogers et al., 1982), few detailed studies are available for the Great Barrier Reef. Here the conditions during the cyclone, the observed effects underwater, and an analysis of changes in the hard and soft coral community for a selection of sites, are described.

Figure 1. **Map of Green Island Reef showing the locations of six sample sites. A = reef flat (less than 1 m), B = leeward bommie (2 m), C = shallow transplant site (2 m), D = deeper transplant site (6 m), E = glass bottomed boat patch ("glassy patch") (2 m), F = south-east slope (3 m).** Figures in brackets are approximate depths at low water.



METHODS

Cover of hard and soft corals was measured using line transect techniques. In August and September, 1985, 20 sites around Green Island reef were surveyed, and the cover of living organisms and substrate types was measured. For each site, a series of four 30 m lines was used. A 30 m tape was attached at random to the substrate and extended along the depth gradient. The length of the target group under the tape was measured.

In February and March 1986, six sites likely to have been affected by the cyclonic seas because of their orientation and/or their relatively shallow depth were surveyed (Figure 1). At five of the sites, only the cover of hard and soft corals was measured, while at the "shallow transplant" site, cover of all substrate types was measured. Corals were identified to genus where possible.

Information on wind speed and direction was provided by the Bureau of Meteorology in Cairns.

RESULTS

Weather conditions

At Cairns airport, there was a period of 11 hours from 1500 hrs, on February 1, until 0200 hrs on February 2, when the wind speed was consistently over 33 km/hr, with wind direction consistently from the north-west. During this time, there was a period of three hours during which winds were consistently gusting to over 66 km/hr, with occasional gusts up to 100 km/hr, still predominantly from the north-west.

The wind direction is significant, since wind-roses showing wind speed and direction for the Cairns region over a 15 year period indicate that the frequency of winds from the west or north-west throughout the year is extremely low, and the wind speed from this direction is also usually low. Thus, strong winds and seas from the north-west are found very infrequently in this part of the Great Barrier Reef.

General observations

General observations were noted at the sites sampled by line transects. At only one site (shallow transplant site) (Figure 1), were there obvious signs of the effects of wave action. The area had been predominantly rubble with Halimeda and low coral cover. After the cyclone, a scouring effect was visible, with large amounts of rubble excavated, apparently to a depth of 300 mm in parts. Most calcareous algae were gone, and the few corals that had been established had mostly disappeared.

Unfortunately, this area had contained coral transplantation experiments, the vast majority of which had vanished without trace, after surviving long periods of very strong south-east winds the previous year. Stakes and ropes marking experimental quadrats had been pulled from the ground, and large amounts of sand had moved into the area.

There was little obvious damage at other sites, although close inspection of the corals revealed that many colonies had suffered broken branch tips. Some dead standing coral skeletons had collapsed, but in many cases the small corals that had settled on the dead corals were still alive. At the seaward site (Figure 1), a tree branch approximately 3 m long, was found trapped under a dead coral colony in 4 m of water.

At the "glass bottom boat patch", where coral cover was higher than other sites sampled, there was damage to branch tips, and some transplanted corals in the sandy areas were partially buried, but again damage was not obvious. At no sites was there a clear indication of damage to the soft coral community.

Line transects

There was no statistically significant decrease in soft coral cover at any of the sites sampled (Table 1).

For hard corals, only the shallow transplant site showed a significant decrease in cover (Table 2).

Because of the apparent changes in substratum types at the shallow transplant site, cover of all substrata were compared before and after the cyclone. There was a significant change in the amount of sand in the area, from 8.5 to 36.9 percent cover (Table 3).

There was also a significant decrease in the number of corals recorded in the line transects. Comparison of the size frequency distribution of intervals of corals demonstrated that the loss was predominantly amongst smaller corals (Figure 2), probably recruits on substrata that was moved around or buried during the cyclone.

Figure 2. Frequency distributions of intercept lengths of hard corals at the "shallow transplant site" before (a) and after (b) cyclone Winifred.

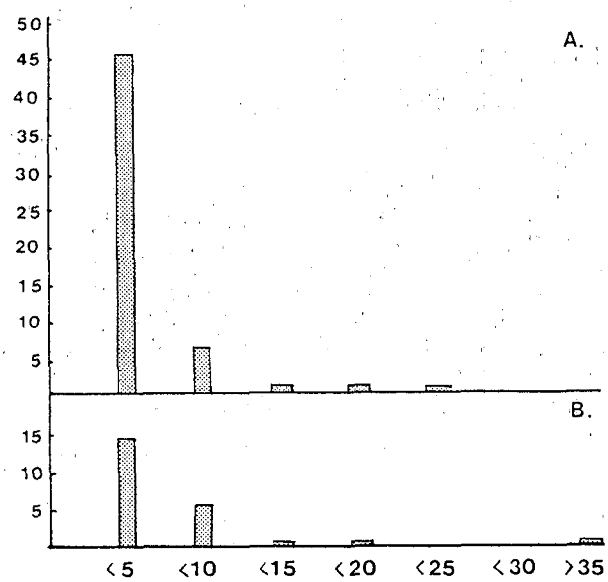


Table 1. Relative cover of soft coral at six sites sampled before and after cyclone Winifred, and the results of T-test for the null hypothesis that there was no decrease in coral cover during the cyclone.

Site	Pre-cyclone Mean cover (%)	S.E.	Post-cyclone Mean cover (%)	S.E.	T	P(T)
Reef flat	17.8	3.4	20.9	4.8	0.55	0.29
Leeward bommie	4.5	2.1	7.5	3.1	-0.78	0.23
Shallow transplant	3.6	2.2	1.4	1.6	0.98	0.19
Deeper transplant	6.9	1.1	7.6	3.2	-0.21	0.42
Glassy patch	17.2	3.5	12.9	3.3	0.89	0.20
South-east slope	4.9	1.4	7.8	2.1	1.13	0.15

Table 2. Relative cover of hard coral at six sites sampled before and after cyclone Winifred, and the results of T-test for the null hypothesis that there was no decrease in coral cover during the cyclone.

Site	Pre-cyclone Mean cover (%)	S.E.	Post-cyclone Mean cover (%)	S.E.	T	P(T)
Reef flat	5.6	1.4	3.8	0.9	1.08	0.16
Leeward bommie	7.4	2.8	3.9	1.1	1.15	0.14
Shallow transplant	2.4	0.2	1.5	0.4	2.26	0.03*
Deeper transplant	5.6	0.8	4.5	0.5	1.16	0.15
Glassy patch	11.3	2.8	9.6	2.3	0.48	0.32
South-east slope	5.5	2.2	4.5	0.5	0.79	0.23

Table 3. Changes in parameters (other than cover of hard and soft coral) at the "shallow transplant" site, and T-test for the null hypothesis that there were no changes in these parameters during the cyclone.

Parameter	Pre-cyclone X	S.E	Post-cyclone $\overline{X}$	S.E.	T	P(T)
Sand cover (%)	8.5	2.9	36.9	2.9	-6.87	0.0005*
Rubble cover (%)	62.4	7.9	51.1	3.8	1.30	0.24
Dead Coral (%)	3.3	2.6	0	0	1.34	0.23
Other cover (%)	19.5	4.7	9.3	3.2	1.78	0.13
Hard corals/30 m	14.8	1.8	5.8	1.1	4.34	0.0004*
Intercept length of Hard Corals (cm)	5.1	0.8	7.9	2.2	-1.18	0.28

DISCUSSION

The effect of cyclone Winifred on coral regeneration at Green Island was slight, and statistically significant changes were restricted to only one of the six areas examined. This was despite the fact that winds of up to 100 km/hr were recorded from a direction other than that of prevailing strong seasonal south-east winds.

This result is surprising in view of the body of literature of cases where cyclonic winds have caused severe damage (Ogg and Koslow, 1978; Stoddart, 1969, 1974; Rogers et al., 1982). In 1980, hurricane Allen caused catastrophic damage to coral reefs in the Caribbean, with recorded wind speeds of 110 km/hr near the study sites (Woodley et al., 1981). However, waves 12 m high were reported to be breaking over the site during the hurricane, while there were no reports of such extreme conditions at Green Island Reef during cyclone Winifred. Green Island is somewhat protected from heavy seas by the proximity of reefs to the north and its closeness to the mainland.

Other reports of cyclone damage to coral reefs indicate variable degrees of damage, depending on the strength of the cyclone and the frequency of storms in the area (Pearson, 1981). In Australia, there are few detailed studies of cyclone damage, and these are summarized in Stoddart (1969), Endean (1976), and Pearson (1981).

A cyclone at Low Isles in 1950, reputed to have caused extensive damage to the coral community, had wind speeds of 85 km/hr. Stephenson et al. (1958) postulated that the serious effects of only a moderately strong cyclone were partly due to the direction of the winds, from the north or north-west, the normally leeward side of the reef (similar to the wind direction during cyclone Winifred).

Connell (1973, 1978) and Woodhead (1971) describe the effects on the recovery of the coral community from cyclones at Heron Reef. Connell notes that the three cyclones that passed through the area during 15 years of his study varied in the extent and severity of their effects. On a reef slope site, coral cover was reduced to less than 5 percent during one of the storms.

The effect of the cyclone on corals at Green Island may have been minor because of the early stage of the reef in the recovery process following the last A. planci infestation. In the five years since A. planci were last seen in great numbers on the reef, corals have recruited successfully (personal observations), but the size of colonies remains small. Such small colonies, if attached firmly to solid substrate, may be less likely to be damaged by the physical pressures associated with large seas than large staghorn or plate Acropora colonies for example.

The main damage observed was from movement of the substratum onto which corals had settled, and some breaking of coral tips. There was little sign of the postulated collapse of dead corals riddled by bioerosion (Endean, 1976), with subsequent loss of colonies that settled on dead colonies. Most successful juvenile coral recruitment at Green Island has been onto dead coral.

REFERENCES

Connell, J.H. 1973. Population ecology of reef-building corals, in O.A. Jones and R. Endean (Eds.) Biology and Geology of Coral Reefs, Volume 2. Academic Press, New York.

Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. Science, 199: 1302-1310.

Endean, R. 1976. Destruction and recovery of coral reef communities, in O.A. Jones and R. Endean (Eds.) Biology and Geology of Coral Reefs, Volume 3. Academic Press, London.

Ogg, J.G. and Koslow, J.A. 1978. The impact of Typhoon Pamela (1976) on Guam's coral reefs and beaches. Pacific Scientist, 32: 105-118.

Pearson, R.G. 1981. Recovery and recolonization of coral reefs. Marine Ecology Progress Series, 4: 105-122.

Porter,J.W.; Woodley, J.D.; Smith, G.J.; Niegel, J.E.; Battery, J.F. and Dallmeyer, D.G. 1981. Population trends among Jamaican reef corals. Nature, 294: 249-250.

Rogers, C.S.; Suchanek, T.H. and Pecora, F.A. 1982. Effects of Hurricanes David and Frederic (1979) on shallow Acropora palmata reef communities: St. Croix, U.S. Virgin Island. Bulletin of Marine Science, 32(2): 532-548.

Stephenson, W.; Endean, R. and Bennett, I. 1958. An ecological survey of the marine fauna of Low Isles, Queensland. Australian Journal of Marine and Freshwater Research, 9(2): 261-318.

Stoddart, D.R. 1969. Ecology and morphology of recent coral reefs. Biological Review, 44: 433-498.

Stoddart, D.R. 1974. Post-hurricane changes on the British Honduras reefs: resurvey of 1972. Proceedings of the Second International Coral Reef Symposium, Brisbane, 473-483.

Woodhead, P.M.J. 1971. Surveys of coral recolonization in reefs damaged by starfish and by a cyclone. Report of the Committee appointed by the Commonwealth and Queensland Governments on the Problem of the Crown-of-Thorns Starfish (Acanthaster planci). Australian Governemnt Printing Service, Canberra.

Woodley, J.D.; Chornesky, E.A.; Clifford, P.A. and others. 1981. Hurricane Allen's impact on Jamaican coral reefs. Science, 214: 749-755.

COMPARATIVE EFFECTS OF CYCLONE DAMAGE TO MANGROVE FORESTS: KATHY VERSUS WINIFRED.

T.J. Smith III
Australian Institute of Marine Science

This paper compares the effects of two cyclones on mangrove vegetation. Cyclone Kathy crossed the coastline of the Gulf of Carpentaria near the mouth of the MacArthur River on March 23, 1984, with winds of 185 km/hr, gusts to 230 km/hr, and a central pressure of 940 mb. Winifred crossed Mourilyan Harbour on February 1, 1986, having winds of 170 km/hr, gusts to 220 km/hr, and a 950 mb central pressure. Kathy's landfall coincided with slack water, whereas Winifred crossed the coast on a falling tide.

Detailed ground and aerial surveys were undertaken in August, 1984, and February, 1986, along the MacArthur River and North Queensland coasts respectively. Massive tree mortality was noted along the MacArthur River. Among the Rhizophoraceae, mortality upstream was significantly greater than at the river mouth (80 ± 20 percent as opposed to 35 ± 20 percent). Mangroves at the river mouth may have been protected from the winds by being flooded by the 3 to 4 m storm surge generated by the cyclone. Averaged over the entire river length, species such as *Excoecaria agallocha*, *Lumnitzera racemosa* and *Avicennia marina*, suffered much less mortality than the *Rhizophora*, *Bruguiera* and *Ceriops* (18.5 ± 11.4 percent against 45 ± 15.3 percent). *Excoecaria*, *Avicennia* and *Lumnitzera* are capable of stump sprouting whereas the other genera are not. This capability probably accounted for the lower mortality observed in the former species.

Mortality in North Queensland's coastal areas (Murray, Tully, Hull, Russell, Johnstone Rivers and Missionary Bay) was less than 0.05 ± 0.04 percent. Those few trees which had been windthrown were invariably located on creek banks or the edge of a light gap where they were not supported by the surrounding canopy. Most trees had suffered small to moderate amounts of defoliation and substantial amounts of leaf litter and small branches were present in the forest floor.

Reasons for the large difference between Kathy and Winifred are most simply explained by the difference in windspeed of the two cyclones. Wind damage to vegetation usually increases dramatically at some threshold value. For mangroves this threshold may be between 170 and 185 km/hr.

EFFECTS OF CYCLONE WINIFRED ON COASTAL AND ISLAND FAUNA

J.G. Blackman, J.W. Winter and B.R. King
Queensland National Parks and Wildlife Service,

ABSTRACT

Cyclone Winifred caused widespread damage to coastal and island vegetation between Bramston Beach and the Tully River. Damage was especially severe in the Mission Beach area. Cyclone Winifred was apparently similar in its effects to earlier severe damage in March, 1918, and March, 1956. The observed damage to lowland forest areas appears to confirm conclusions by Webb (1958), that tropical cyclones "...are a potent ecological factor which regularly upsets forest equibrilium, with far reaching consequences for the regeneration, suppression and reproduction of species".

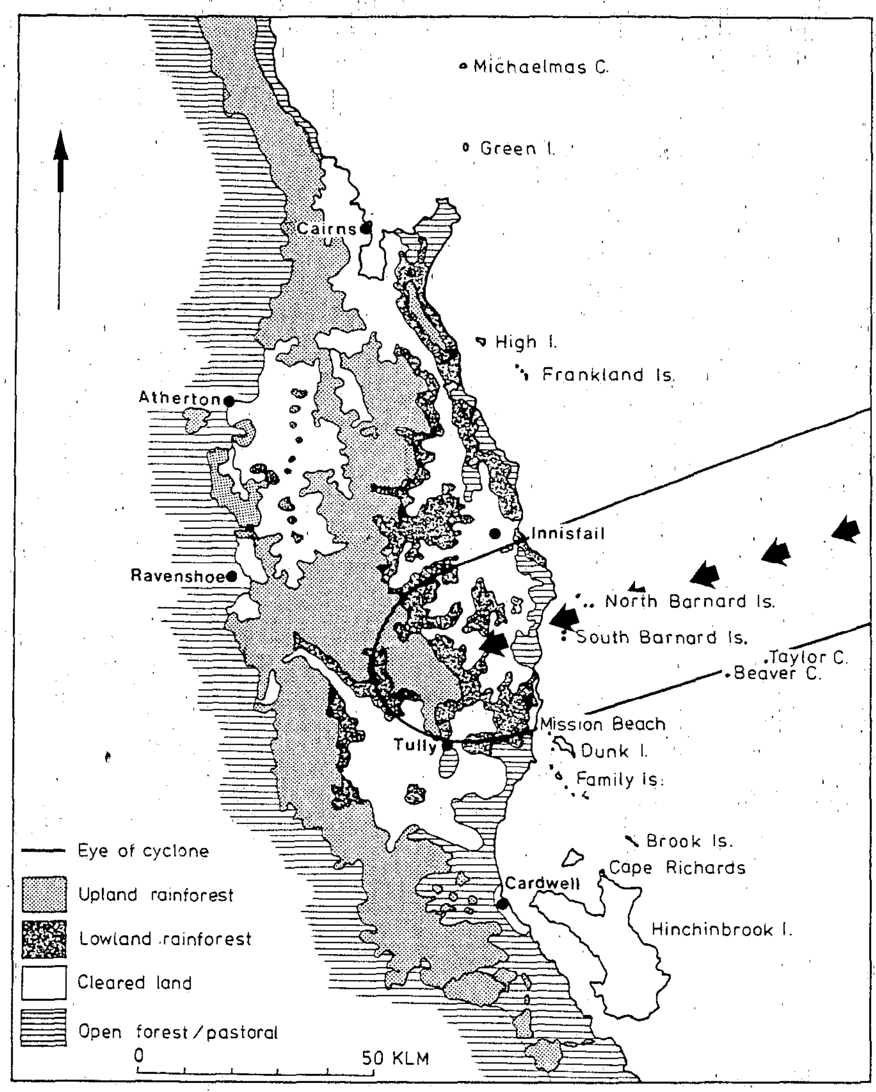
The major short term effects on fauna is thought to be through direct mortality during the cyclone and a variety of direct and indirect aftermath effects resulting from disturbance to habitat. Certain species of fauna are more susceptible than others. These include species which are dependent on closed forest for essential habitat and food supplies, have limited mobility, or are breeding. In this respect the Cassowary, Musky Rat-kangaroo and the Torresian Imperial Pigeon are three species which are considered to be especially vulnerable.

There is almost nothing known regarding the effects of cyclones on most frugivirous and nectivorous species, other than that many vacate cyclone devastated habitat. Similarly there is little known about the re-establishment and subsequent composition of communities, or the eventual fate of the former occupants.

INTRODUCTION

Cyclone Winifred crossed the North Queensland coast in the vicinity of Innisfail on February 1, 1986. The cyclone caused widespread damage to extensive tracts of vegetation in coastal areas, and on some offshore islands between Bramston Beach and the Tully River (Figure 1). Subsequent observations of the nature and extent of this damage provided an opportunity to interpret the impact of severe cyclones on fauna, particularly those species associated with closed forest habitat in the area between Townsville and Cooktown. In general, information on the effect of cyclones on terrestrial mainland and island fauna in north-east Queensland is limited and mostly anecdotal. For example, the works of Banfield (1925) and Wittingham (1958). Elsewhere in Australia more detailed information has been reported (Marsh et. al., 1984); Limpus and Reed, 1985; and Langham, 1986.

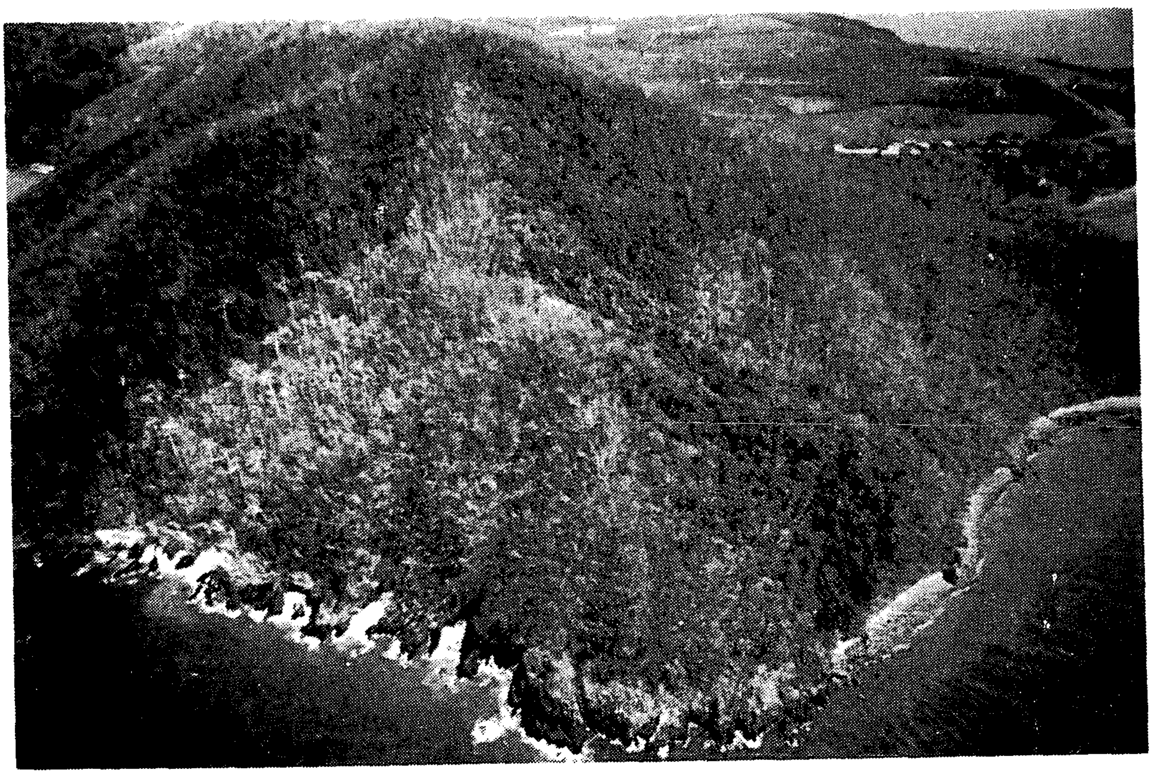
Figure 1. Distribution of forrested and cleared land in relation to the track of cyclone Winifred.



Tropical cyclones, and the widespread flooding which often accompanies them, are a significant environmental feature of northern Australia. According to Lourensz (1981), the north-east coast of Queensland experiences the highest incidence of cyclones in Australia , with 43 percent (115 cyclones) of all the cyclones occurring in northern Australia in the period 1909 to 1980. On average, the cyclone season begins in late November and continues through to April. The months of greatest activity are January to March. Cyclones with wind speeds in excess of 60 km/hr are regularly experienced. In the last 120 years, notably destructive cyclones have been recorded in 1884, 1896, 1899, 1903, 1918, 1920, 1923, 1928, 1956 and 1971 (Webb, 1958; Louresz, 1981). These records indicate that Winifred was similar to the cyclones of March, 1918, and March, 1956 (Webb 1958). These were amongst the most destructive and caused damage to the tropical rainforest of the Innisfail region.

The lowland area between Cairns and Tully extends for approximately 100 km as a virtual corridor bounded on either side by the north-south coastal ranges. The peculiar topography of the area is responsible for surge effects which increase the velocities of cyclonic winds. Following cyclone Agnes in March, 1956, Webb (1958) attributed the seemingly erratic pattern of damage in lowland rainforest - in strips of irregular width and aspect, but more common on exposed ridges than gullies - to topographic features which intensified turbulence. Thus defoliation and shattering of tall trees was less extensive on the sheltered valley bottoms than on the exposed adjacent slopes. A similar pattern of damage was evident throughout the area affected by cyclone Winifred (Figure 2).

Figure 2. Dunk Island two weeks after cyclone Winifred, showing the pattern of vegetation damage typical on exposed ridges. Photograph by D. Savage Q.NPWS.



This paper briefly summarises the impact of cyclones on particular terrestrial habitat of coastal lowlands and islands in north-east Queensland and identifies specific problems for wildlife. It is concerned with two aspects; firstly, an overview of what is known about the physical and ecological effects of cyclones on lowland closed forest (the most extensive and noticeably disturbed habitat) of the area; and secondly, the perceived effects of cyclones on mainland and island fauna, especially those species which are potentially vulnerable. The intention is to provide an ecological perspective for assessing the impact of cyclones on bird and mammal fauna. The emphasis is towards identifying any patterns which can aid management of wildlife and their habitat in areas subject to frequent cyclones.

EFFECTS ON CLOSED FOREST HABITAT

Physical effects of cyclone Winifred

Throughout the mainland area effected by cyclone Winifred (Figure 1) there was variation in the extent of damage to vegetation. Areas of extensive damage included coastal sections of the Walter Hill Range, Bictons' Hill, Clump Point and the Mission Beach, Narragon Bay, Bingil Bay, and Garners Beach areas (Figure 3). Further inland there was severe damage to the valleys associated with Downey and Jarra Creeks. The Josephine Falls National Park suffered heavy damage. A notable feature is that there was greater than 90 percent defoliation of the middle and upper strata of forests over very large areas. Branches and twigs within the canopy were extensively damaged; by comparison, there was much less structural damage to tree trunks. Nonetheless there were local pockets where the forest had been entirely flattened.

Figure 3. Damage to closed forest habitat near Garners Beach, four weeks after cyclone Winifred.

Similar damage occurred on continental islands and sand cays during the cyclone. Vine forests on continental islands (North and South Barnard Islands, Dunk and Purtaboi Islands) were severely damaged through defoliation, loss of branches, windthrows and windburn. However in some sheltered areas, usually on the western side of the island, vegetation was relatively undamaged (Taplin and Osborne, 1986). Erosion was confined to sand spits. Sand cays (Upolu, Beaver and Taylor Cays), on the other hand were severely eroded. All three sand cays were inundated, and Taylor Cay was eroded to below high water level. Parts of Michaelmas Cay and Green Island, some 100 km north, were also extensively eroded (Q.NPWS, 1986).

Ecological role of cyclones

The ecological role that cyclones play in the tropical lowland rainforest of North Queensland has been interpreted by Webb (1958), following his observations in the wake of cyclone Agnes, in 1956. It is relevant to summarise his conclusions in the context of the present cyclone. Webb concluded that the severity of damage is related to local topography and aspect, and that the structure of certain forests is the result of previous cyclone damage. In this respect, he recognized three notably distinct structural formations. In certain topographic positions prone to intense localised wind pressures during cyclones there was development of "cyclone scrubs" typified by a vine understory which extends upwards as part of an uneven vine draped canopy. In more sheltered areas, the rainforest was typified by a type of mesophyll vine forest with an even canopy level averaging 10 to 25 m high with a dense lawyer vine Calamus australis understory about 3 m high. On exposed spurs of the coastal ranges, the structure of the forest was modified by the appearance of emergent trees 20 to 30 m above a lower, somewhat uneven canopy 12 to 18 m high.

In the period after cyclone Agnes, Webb noted the following sequence in the recovery of the rainforest. Within two weeks, leaf sprouting occurred on some denuded trees, and eventually became general. Some species, Bangalow Palms Archontophoenix alexandrae for example, flowered immediately after the cyclone. Within nine months, rampant vine growth had obliterated most signs of the damage. Patches of moribund trees were evident within 15 months. This sequence has to date been paralleled by the recovery of vegetation following cyclone Winifred.

Elsewhere, Dittus (1985a) has provided quantitative data on the impact of a cyclone in November, 1978 on a dry evergreen forest in Sri Lanka. Damage was similar to that described above. Tree species in the upper layers had significantly more falls and post-cyclone mortality than trees in the more sheltered subcanopy and shrub layers.

In summary, the physical effect on closed forest ranges from the uprooting of large trees (particularly when the soils are sodden), snapping off and shattering of tree trunks above ground and extensive defoliation. The resultant opening-up of the forest canopy leads to the rapid establishment of light tolerant species, particularly vines. Also, when periods of dry, hot, windy weather follow cyclonic damage, the abundance of drying vegetation provides ideal conditions for the entrance of fire into the normally fire resistant rainforest.

Both Webb and Dittus consider that recurrent cyclone damage is an important factor in succession and variations in the species composition, particularly in the upper canopy of these forests.

Finally, and most significantly in the present context, Webb argues that "... the periodicity of severe cyclones has prevented the development of a simplified stable climax forest; and concludes that cyclones are a potent ecological factor which regularly upset forest equibrilium, with far reaching consequences for the regeneration, suppression and reproduction of species". Observations in the wake of cyclone Winifred would appear to substantiate Webb's conclusions.

From this perspective cyclones, although seemingly catastrophic to the casual observer, represents a mechanism which has been instrumental in shaping the structure and composition of these lowland forest habitats. We are of the opinion that cyclone Winifred has been a spectacular demonstration of this mechanism in action.

This is of course, a purely ecological and somewhat historical view of cyclones, which in present times must be interpreted within the context of a greatly altered environment. In short, it is not known to what extent European man's disturbance and fragmentation of the forest may now be influencing the effects of cyclones and perhaps altering the process of an otherwise natural succession. This may well be the most important aspect facing management in relation to the effects of present and future cyclones.

EFFECTS ON FAUNA

Observations following Winifred

On the mainland, the species most obviously effected was the Cassowary Casuarius casuarius. This was particularly evident in the Mission Beach area, where there was a marked increase in the number of birds emerging from the rainforest margins to scavenge for food around rural and urban habitation. Many of these birds were obviously hungry, and apparently stressed. The size of the Cassowary population in the area is not known. However, by mid-May, a total of 93 adults and 41 immatures were being fed in the Innisfail, Mission Beach, Garners Beach and Tam-O'Shanter Range areas, under a sustenance feeding programme organised by the Queensland National Parks and Wildlife Service. No deaths of Cassowaries were reported.

There have been only cursory observations of the effects on a variety of frugivorous and nectivorous species. Mortality amongst such species was not reported and would, in any case, remain largely undetected. The most general observation has been that the majority of rainforest dependent species have apparently vacated severely damaged areas of rainforest habitat. Taplin and Osborne (1986), reported that "... no small passerines or other forest birds were seen at any of the islands visited except in the sheltered areas where the vegetation was little disturbed. Kent Island was the only island at which a representative samples of the species expected on the island was found."

Bird deaths were reported from several islands (Sisters and Dunk Islands), with approximately 50 each of dead Torresian Imperial Pigeons (Ducula spilorhoe) and Bridled Terns (Sternus anathetus) (Q.NPWS, 1986); Kent Island, with six dead Birdled Terns (Taplin and Osborne, 1986).

Spectacular declines were recorded in some colonies of the Torresian Imperial Pigeon. On North Brooke Island, 21 800 pigeons were counted on January 7, 1986; while on March 18, 1986 only 36 pigeons were present (A. and M. Thorsborne, pers. comm.). On the North and South Barnard Islands, 5 000 pigeons were estimated in November 1986; on February 7 and 8, 1986 there were no more than six pigeons on any of these Islands (Taplin and Osborne, 1986).

General impact on fauna

The earliest description of the effects of cyclones on lowland closed forest presents a picture of a habitat prone to relatively frequent and high levels of disturbance. What follows is an attempt to combine existing information and general principals to interpret the effect of this disturbance on fauna.

The major short term effects on fauna are thought to be through direct mortality during the cyclone, and a variety of direct and indirect aftermath effects resulting from disturbance to habitat. All species are effected to some extent, but as might be expected those species with a particular dependence or attachment to cyclone devastated habitat are considered most susceptible.

In this respect, it is useful to consider the ways in which cyclones affect closed forest as animal habitat and the types of animals most likely to be seriously affected.

The impact of cyclones on the forests as animal habitat can be summarised as follows;

- defoliation and destruction of the forest canopy, alters the climate of the forest by exposing the forest floor to longer periods of direct sunlight and by raising temperatures;
- physical destruction of forest vegetation inhibits the mobility and foraging abilities particularly of ground dwelling species;
- destruction of food supplies, disturbance to the cycles of foraging of food trees and subsequent changes in the composition and distribution of fruiting species disrupts the feeding of animals; and
- preferred shelter of a number of species (particularly canopy dwellers) is diminished.

The overall effects of these changes are to increase physiological stress through dehydration and/or starvation; to increase mortality through predation and; to cause a large proportion of species (birds, for example) to vacate the habitat.

Finally, animals will be susceptible to the effects of cyclones through one or several of the following;

- restricted distributions and dependence on closed forest habitat;
- limited ability to disperse rapidly;
- obligate or specialised food requirements;
- exposure to physical injury during the cyclone;
- exposure to increased natural mortality in the wake of the cyclone; and
- reduction in breeding success.

Animals considered vulnerable

There are three species which we consider are vulnerable to the effects of cyclones such as Winifred. These are the Cassowary (Casuarius casiarius), Musky Rat-kangaroo (Hypsiprymnodon moscatus) and the Torresian Imperial Pigeon (Ducula spilorrhoa).

Cassowary

The Cassowary is a large, apparently resident species. It is restricted to closed forest habitat and its diet is principally closed forest fruits. This habitat has been fragmented by the clearing of lowland forest (Figure 1) so that a large proportion of the lowland population is obliged to remain in disturbed habitat in the wake of a cyclone. Loss of even a comparatively low number of individuals would be significant to the local population.

During and after a cyclone the animal is considered susceptible to exposure, starvation and heat stress, and to increased predation by domestic dogs.

Musky Rat-kangaroo

The Musky Rat-kangaroo is a small, ground dwelling, diurnal mammal. It is a resident species restricted to closed forest habitat where it prefers moist areas and forages on the forest floor. Like the Cassowary, its habitat is fragmented and lowland populations are obliged to remain in disturbed habitat in the wake of a cyclone. Because of its diurnal habitats, destruction of the forest canopy would considerably increase predation on this animal.

During and after a cyclone, the animal is considered susceptible to exposure, possibly heat stress, and predation.

Torresian Imperial Pigeon

The Torresian Imperial Pigeon moves to the north-east Queensland area from Papua New Guinea in spring. The pigeons roost and breed in large colonies in mangroves and closed forest on low wooded and continental islands in spring and summer. The species is an obligate fruit-eater and moves daily to the mainland to feed on rainforest fruits. Because of its habit of concentrating in large colonies, the species is susceptible to high mortality from early cyclones. However, the pigeons normally begin to leave the area in late January, so the large colonies are dispersing during the period of greatest cyclone frequency. Pigeons returning to cyclone disturbed habitat in the following spring, as well as pigeons remaining in the wake of a cyclone, would be faced with a drastically reduced food supply.

The species is considered susceptible to high mortality in the breeding and roosting colonies during a cyclone, and to possible food shortage on their return to an area later in the year.

Other species

There is almost nothing known regarding the effects on a variety of frugivorous and nectivorous species other than that many vacate cyclone devastated areas, or congregate at pockets of undisturbed habitat.

Sea birds

Up to this point, the impact on sea birds has not been considered. The potential for significant mortality will be greatest for those species which concentrate and breed in large colonies during the cyclone season. For species such as the ground nesting terns, direct mortality of adults and young through exposure and the reduction in breeding success through destruction of nests and eggs, are important factors. There may also be the additional aspect of relative food shortage after a cyclone because of conditions unfavourable to feeding. This may compound mortality of dependant young through starvation. Following cyclone Simon at One Tree Island in February 1980, Langham (1986), recorded weight losses in the chicks of three tern species because parent birds could not forage during and after the cyclone. Breeding may also be affected through loss of breeding habitat resulting from erosion.

CONCLUSIONS

Fauna communities occupying areas exposed to severe cyclonic disturbance almost certainly comprise species which in one way or another take advantage of such a habitat. It is reasonable to assume that for at least a proportion of these species the effects of cyclones are a natural cause of mortality which may be spectacular but is nonetheless short term. Clearly there should be little reason for concern for the viability of species or communities which have evidently adapted to a habitat that is prone to regular disturbance. On the other hand, some species may now be increasingly vulnerable to the effects of cyclones because factors which might have compensated for such mortality in the past have now altered. These are nearly all the result of man's activities, for example, the fragmentation and reduction of mainland habitat, and disturbance at breeding colonies.

The question in relation to the effects of cyclones on wildlife is twofold. Firstly, do cyclones cause sufficiently high levels of mortality to be a significant factor in threatening local populations; and secondly, does cyclone disturbance significantly alter the subsequent occupancy of habitats by fauna communities?

In the instance of the Cassowary and the Musky Rat-kangaroo, the entire local population is exposed to the effects of cyclones. These effects are exerted firstly during the cyclone and for a prolonged afterwards as the result of alteration to habitat. It is not known to what extent either species traditionally sought shelter in refuge areas undamaged by cyclones. It is almost certain that the option of moving to alternate shelter is now much reduced as the result of rural development and fragmentation of closed forest habitats. It is unlikely that the Rat-kangaroo is able to disperse out of a cyclone devastated area.

In the instance of the Torresian Imperial Pigeon and seabirds, the mobility of the adults and fledged immatures will allow them to rapidly vacate an area during or before a cyclone. However breeding success of local populations could be partially or wholly reduced, especially during an early cyclone.

It is worthwhile noting that disturbance of such animals at other times of the year can reduce their ability to cope with occasional high mortality.

The pattern that we discern is one of relatively few species being severely effected by cyclones. For these species the effects are likely to be limiting only where other factors have made the animal more susceptible to occasional high mortality, whatever the cause. The most vulnerable appear to be species which are restricted to a particular habitat that has become limited. The Cassowary and Musky Rat-kangaroo are two examples. Other species notably the pigeons and colonial nesting seabirds are vulnerable because of their habit of concentrating in large numbers in comparatively local situations. Whether or not they can withstand occasional high mortality depends on the current status of each species.

The re-occupancy of cyclone damaged habitat is difficult to assess. Given that cyclones maintain a process of succession within the closed forest habitat, it is unlikely that the evacuation of cyclone damaged areas by local populations is anything more than short term. What is not known is the subsequent composition of re-established communities, or the eventual fate of the former occupants.

REFERENCES

Queensland National Parks and Wildlife Service. 1986. Impact of Cyclone Winifred on Cairns Section islands and reefs: Low Islets to Dunk Island. Quarterly Report, January - March 1986: Day-to-Day Management, Great Barrier Reef Marine Park, Attachment C. Internal Report, Marine Parks Section, Queensland National Parks and Wildlife Service.

Banfield, E.J. 1925. Last Leaves from Dunk Island. Sydney: Angus and Robertson.

Dittus, W.P.J. 1985. The influence of cyclones on the dry evergreen forest of Sri Lanka. Biotropica, 17(1): 1-14.

Laughan, N. 1986. The effects of cyclone "Simon" on terns nesting at One Tree Island, Great Barrier Reef, Australia. Environment, 86(1):53-57.

Limpus, C.J. and Need, P.C. 1985. Green Sea Turtles Stranded by Cyclone Kathy on the South-Western Coast of the Gulf of Carpentaria. Australian Wildlife Research, 12:523-533.

Lourensz, R.S. 1981. Meteorological Summary. Tropical Cyclones in the Australian Region, July 1909 to June 1980. Bureau of Meteorology, Department of Science and Technology: Canberra.

Marsh, H., Freeland, W.J., Limpus, C.J., and Reed, P.C. 1984. The stranding of dugongs and sea turtles resulting from Cyclone Kathy, March 1984: a report on the rescue effort and biological data. Unpublished report to the Australian National Parks and Wildlife Service.

Taplin, A. and Osborne, K. 1986. Report on a field trip to the Barnard Island, 6-8 February, 1986. Internal report to the Regional Director, Northern, Queensland National Parks and Wildlife Service.

Webb, L.J. 1958. Cyclones as an ecological factor in tropical lowland rainforest, north Queensland. Australian Journal of Botany. 6: 220-228.

Winter, J.W.; Bell, F.C.; Pahl, L.I. and Atherton, R.G. (1984). The Specific Habitats of Selected Northeastern Australian Rainforest Animals. Report to the World Wildlife Fund of Australia.

Wittingham, H.E. 1958. The Bathurst Bay Hurricane and associated storm surge. Australian Meteorological Magazine. 23: 14-36.

ENVIRONMENTAL LOSS - THE HIDDEN ASPECT OF POST-NATURAL DISASTER PSYCHOSOCIAL DISTRESS

P. Foley and R. Thorpe
James Cook University of North Queensland

ABSTRACT

Loss is an inevitable consequence of the impact of a tropical cyclone on a community. This loss can be a mixture of both monetary and emotional loss. Some of this loss may be retrievable, other aspects will not be. But a substantial proportion of the perceived loss following a natural disaster will remain in the category of uncertain retrievability unless some clarification is received.

The area of environmental loss is within this category. Environmental loss can be defined as a change in the natural environment due to a disaster that are appraised negatively by an individual and may cause disruption to routine or self-identity maintaining behaviours and activities. How people cope with such a loss varies, and can range from withdrawal to active coping. An example of active coping is the programe to feed the Cassowaries.

In the input of legitimated clarification is essential to the maximization of positive coping styles following a natural disaster like Winifred. The discussion will centre on the role of the Great Barrier Reef Marine Park Authority in encouraging positive coping styles in relation to environmental loss and the Authority's function of clarification in lessening its impact.

CYCLONE WINIFRED - A WILD LADY'S LIST OF DESTRUCTION

K. G. McClymont
Great Barrier Reef Marine Park Authority

Cyclone Winifred's path through the Great Barrier Reef, across islands and eventually the coastline, was littered afterwards with examples of her destructive forces. This report is a summary of the damage reported to the Authority that occurred to reefs and marine life in the Great Barrier Reef Marine Park, and to features associated with the Marine Park and its use. It also addresses some management implications of the damage. It makes no attempt to put dollar values on the damage.

Both natural and man-made features suffered damage to varying degrees.

DAMAGE TO NATURAL FEATURES

Reefs in or very close to the direct path of the cyclone suffered severe but apparently localised physical damage to structure, corals, fish and other marine life.

Reef and cay damage

- Damage was largely restricted to the more exposed windward (north-eastern and north-western) areas of the reefs, especially the reef fronts, forereef crests and tops. (Potter, Gilbey and Feather Reefs were seriously effected in this manner).

- The back-reef areas of two of the reefs in or very near the direct path of the cyclone (Potter and Feather) surveyed one week after the cyclone were virtually untouched except for some sand/rubble deposits off the reef edge and occasional broken branching corals (presumably broken through impact by coral debris from the reef front).

- Other reefs in or near the cyclone path to *suffer* significant physical damage included, Taylor, Farquarson, Eddy, Nathan, Ellison and Beaver Reefs (some of the reefs surveyed since the cyclone). The main damage to these reefs was sediment scouring, overturning of bottom material, overturned plate corals, broken branching corals and disturbance of clams.

- The size of the cay on Taylor Reef was considerably reduced and is now awash at some low tides). There was also a slight reduction in the size of the cay on Beaver Reef.

- The reefs around the Franklin Islands had damage to corals including large plate corals overturned, and broken branching corals.

- Reefs (and cays) some distance away from the cyclone path also suffered some damage, although not nearly as extensive as the reefs in or near Winifed's path. The north-eastern and northern sides of John Brewer Reef, off Townsville, had a considerable number of large plate corals overturned, and the northern sides of Grub and Bowl Reefs had coral cover damaged in patches. Michaelmas Cay, off Cairns, had some erosion visible on the cay three days after the cyclone, particularly on the south-west tip. Green Island had vegetation damage on the western side and some trees uprooted on the rest of the island.

- Reports from Myrmidon Reef indicated no significant damage had occured there.

Marine life damage

- It is probable that marine life, such as fish, molluscs, crustacea and others, on reefs directly in the path of the cyclone would have been significantly damaged, but the extent of the damage is hard to determine without detailed studies.

  Damage included:

- One week after the cyclone passed, damage to marine life was obvious on Potter, Gilbey and Feather Reefs. On these reefs, large fish were seen with obvious impact damage on their bodies.

- Very few fish were seen on the reef fronts and many of the other marine life species including echinoderms, molluscs, and crustaceans, usually obvious in such areas were notably absent.

- Some clams were observed which had apparently been dead a very short time, as no algae was growing on the insides of the shells.

- Of particular note on the reefs surveyed was the extensive growth of algae on all newly broken coral or substrate surface which had appeared within one week of the cyclone.

DAMAGE TO MAN-MADE FEATURES

Resort and tourist facility damage

- Dunk, Bedarra and Orpheus Islands - some minor building and/or equipement damage. The main damage on Dunk and Bedarra was to the vegetation and aesthetics, with some beach erosion.

- A glass bottomed boat was washed away from Taylor Reef and recovered at John Brewer Reef.

Vessel damage

- The 20 m vessel MV 'Quick Cat' had its front bollards and stanchions ripped off while tied up in Mourilyan Harbour.

- Several trawlers in Mourilyan Harbour were sunk, severely damaged or lost.

- Several vessels anchored off Green Island were damaged.

- Several vessels anchored at Dunk and Bedarra Islands were sunk, damaged or dragged moorings.

Scientific equipment and project damage

- A barge with drilling equipment on loan to James Cook University from BMR for use in crown of thorns studies was washed away from Green Island and recovered several days later at John Brewer Reef.

- JCU lost some satellite receiving equipment off Innisfail.

- The Pacific Clam Trust project off Fitzroy Island lost all its giant clam broodstock and juvenile clams through damage to its floating holding tank barges.

- At the Seafarm clam project at Flying Fish Point, 21 of its 33 giant clam broodstock died due to lowered salinity and high silt content of the only available seawater (due to the heavy rain), and the holding tanks were damaged (16 tanks collapsed and all contents were lost).

Other damage and incidents

- Drums of toxic agricultural chemicals were washed out to sea from near Cardwell.

- A barge from Bougainville Reef in the Coral Sea was separated from its moorings/mothership.

- Heavy siltation of offshore waters for considerable distances off the coast and a great deal of debris from the mainland was observed one week after the cyclone (coastal debris was even found off John Brewer Reef, well south of the cyclone's path).

SOME IMPLICATIONS FOR MANAGEMENT OF THE MARINE PARK

It is very difficult to determine clear cut implications of Winifred's damage but a few possibilities are listed below.

Research and monitoring

- The reef damage will provide an opportunity for day-to-day management staff to monitor the recovery of hard hit reefs. Also, the recovery of those reefs which are popular tourist destinations, Beaver Reef for exapmle, could be compared with recovery rates of little used reefs to see if there are any differences.

- The monitoring of the recovery of damaged reefs could also provide opportunistic data which could be of use in present crown of thorns studies.

- Another research opportunity would be the comparison of reefs which had been hard hit by crown of thorns (COT) before damage by Winifred, with reefs damaged by Winifred without prior COT damage. This may indicate whether or not previous COT attack predisposes a reef to greater susceptibility to cyclone damage.

Tourism

- As no popular tourist cays were significanty damaged, there are no apparent cay management implications, except for the possibility that the damage to Taylor Cay may have had an influence on the decision by Avago Holdings to utilise Beaver Cay for its tourist operations.

- There may be a case for ensuring that tourist facility moorings be of a sufficient standard to withstand cyclonic conditions to prevent facilities breaking away and possibly doing damage to reefs or other facilities. However, as most tourist operators would probably take precautions already to prevent valuable facilities from being damaged, (for example, by taking them to protected anchorages when a cyclone is imminent), this may not be necessary.

Mariculture

- The damage to clam projects is of concern, particularly as a significant number of adult giant clams were killed. However, it is probable that it would not be economically or otherwise feasible to force the operators of clam projects to plan and build their facilities to withstand cyclonic conditions when there is only a small chance of a repeat of the conditions associated with Cyclone Winifred.

INFORMATION SOURCES

- Australian Institute of Marine Science/Great Barrier Reef Marine Park Authority survey of reefs off Innisfail 7-8 February, 1986.

- GBRMPA survey of Taylor, Beaver, Farquarson and Eddy Reefs 25-26 February.

- Queensland National Parks and Wildlife Service - Cairns.

- Coastwatch surveillance reports.

- Seafarm Pty. Ltd. (Richard Braley).

- Personal communications from - Doug Tarca (Reef Link - Townsville), Perry Harvey (Friendship Cruises - Mission Beach), Wayne Williams (Mike Ball Watersports - Townsville), and Bruce Marcum (Pacific Clam Trust - Cairns).

- Personal observations.

ISLANDS AND REEFS SURVEYED FOR CYCLONIC DISTURBANCE

F. Muir
Queensland National Parks and Wildlife Service

Reconnaissance of certain islands and reefs likely to be affected by cyclonic disturbance, offshore between Port Douglas and Mission beach, were carried out by Service Officers.

Table 1 lists the islands and reefs visited, the method of surveillance, and date of visit.

For all sites visited, the aerial survey, ground reconnaissance and underwater manta-tows provided only a rapid indication of the overall type and extent of disturbance.

Quantitative surveys that could indicate specific areas and scales of disturbance were only carried out at two locations; Michaelmas Cay and Green Island. Only at these sites did recent pre-cyclone data exist that would allow before and after comparisons. Specifically, this data related to Green Island cay morphology and sea-bird populations at Michaelmas Cay.

MICHAELMAS CAY

The sand spits on either end of the cay have been re-oriented to form a crescentic shaped cay. A steep erosional scarp 1.5 m high had been cut into the beach face and vegetated area at the north-west end of the cay. The distance between the high water mark and the vegetation edge on the northern beach was 4 m, this distance was approximately 10 m in late January, 1986.

A bank of vegetation 5 m high, adjacent to the northern beach was partly smothered by wind-blown sand. Vegetation on the western quarter of the cay was noticeably windburnt, sand smothered and sparse. Vegetation on the remainder of the cay appeared unchanged. There was no evidence of storm waves having washed over the top of the cay.

In comparison with sea-bird counts conducted over the past 18 months, the post-cyclone counts indicate that the Common Noddy nesting activity has been delayed and reduced in actual numbers nesting or occupying sites.

The peak nesting period in 1985 was in February, with 5 800 breeding pairs present. On the February 4, 1986, only 800 pairs were nesting or occupying sites. By late March, the number of pairs had increased to 2 100.

The exact reasons for this interruption are not easily identified, but are probably a direct effect of the cyclone.

Data for the two other major species nesting on the cay (Sooty Terns and Crested Terns), indicate no significant difference in numbers present or nesting patterns.

Table 1. Islands and reefs reconnoitred by Q.NPWS after cyclone Winifred.

Location	Date	Method of surveillance		
		Aerial Survey	Ground Recon.	Underwater
HIGH CONTINENTAL ISLANDS				
High	5.2.86	X		
Normanby	5.2.86	X		
Russel	5.2.86	X		
Nth Barnards	5.2.86	X		
Stephens	5.2.86	X		
	20.2.86		X	
Sisters	5.2.86	X		
	20.2.86		X	
Dunk	5.2.86	X		
	20.2.86		X	
SAND CAYS				
Low Islets	5.2.86	X		
Michaelmas	4.2.86		X	
	5.2.86	X		
Upolu	4.2.86		X	
	5.2.86	X		
Green	4.2.86		X	
	5.2.86	X		
Taylor	5.2.86	X		
	12.2.86		X	
Beaver	5.2.86	X		
	12.2.86		X	
REEFS				
Hastings	4.2.86		moorings only checked	
	5.2.86	X		
Green	4.2.86		moorings only checked	
	5.2.86	X		
Taylor	5.2.86	X		
	12.2.86			X
Beaver	5.2.86	X		
	12.2.86			X

GREEN ISLAND

Vegetation damage was the most severe on the western side of the island with the foreshore vegetation for 200 m, being approximately 50 percent defoliated and salt abraded. Two trees had fallen across the Green Island Resort staff quarters. No trees were observed to have fallen in the National Park area, however, five large limbs were removed from across tracks.

Beach profile surveys were carried out pre-cyclone (November 20, 1985) and post cyclone (February 6, 1986). Table 2 summarises the extent of beach profile change for geographic sections around Green Island.

Table 2. Summary of Green Island cay profile changes between November 21, 1985 and February 6, 1986.

Q.NPWS sites*	Distance of beach crest removed (m)	Foreshore beach face (net change) (m)	Nearshore intertidal (net change) (m)
North-western corner			
2.5	1.0	+ 11.0	N/A
3.0	17.0	- 60.0	N/A
3.5	6.0	- 12.0	N/A
Northern side			
4.0	0	- 8.0	N/A
5.0	0	- 4.0	N/A
Eastern corner			
6.0	1.5	0.0	+ 7.0
7.0	1.0	- 5.0	0.0
8.0	0	- 3.0	0.0
Southern side			
9.0	0	- 2.0	N/A
10.0	0	- 1.0	N/A
South-western corner			
11.0	0.2	- 1.0	0.0
12.0	0	- 1.0	0.0
13.0	0	+ 4.0	+20.0

* Q.NPWS permanent profile sites (by code number).

Key: + = accretion
- = erosion

POSSIBLE EFFECTS OF CYCLONE WINIFRED ON CIGUATERA ENDEMICITY AT SUDBURY REEF, NORTH QUEENSLAND

R.J. Lewis, J.B. Burke and N.C. Gillespie
Queensland Department of Primary Industries

Ciguatera poisoning is caused by eating certain fishes from coral reef waters, and is common along the far northern and eastern coastlines of Australia. The symptoms of the disease involve neurological and gastro-intestinal disorders with normal recovery usually requiring between several days and several weeks. Ciguatera incidence in some parts of Queensland approaches three cases per 10 000 persons (Capra and Cameron, 1985). It is now the greatest single factor affecting the marketing of tropical reef fish and species such as the narrow-barred Spanish Mackerel. The value of the commercial catch for this fishery in the Great Barrier Reef Region in 1979-80 was $6 million. Other fisheries affected but not included in the Great Barrier Reef Region are; the mackerel fisheries of Hervey Bay and the remainder of south-eastern Queensland. Ciguatera has a considerable effect on consumer confidence in seafood and the prospect of legal action is of considerable concern to the marketing sector.

The principal toxin responsible for ciguatera is ciguatoxin but other toxins (maitotoxin for example) may be involved. Recent work has shown that ciguatoxin is indeed the toxin responsible for ciguatera in Queensland (Lewis and Endean, 1983 and 1984). A benthic dinoflagellate, *Gambiordiscus toxicus*, has been implicated with ciguatoxin production in French Polynesia (Yasumoto *et al*., 1977). Gillespie *et al*. (1985a) examined the distribution of benthic dinoflagellates, and found *G. toxicus* to be widely distributed along the Queensland coast.

Man-made as well as natural reef disturbance in the form of dredging and blasting of channels, storms and the anchoring of ships often precedes the occurrence of ciguatera outbreaks. It has been suggested that this can be explained by the colonisation of "new surfaces" (Randall, 1958) by macroalgae which attract epiphytic micro-organisms such as *G. toxicus* (Yasumoto *et al*., 1980). There have been few reports of a direct link between cyclones and ciguatera. Bagnis (1981a,b) used epidemiological data to demonstrate that natural disturbances in the Marquesas Islands have often been followed by an increased incidence of ciguatera in the short and longer term.

Previously the effect of man-made reef disturbance on Hayman Island on macroalgal flora and populations of benthic dinoflagellates has been examined (Gillespie *et al*., 1985b). At this site human perturbation had no significant influence on either the macroalgal community or the benthic dinoflagellate populations and did not cause an increase in ciguatera endemicity.

Coral reefs in the Cairns area had been surveyed for G. toxicus populations in October, 1983. Low population densities up to 50 per gram of algae substrate were found at that time. One of the sites examined was on the north-west edge of Sudbury Reef which in February, 1986 suffered some effects of cyclone Winifred. This area was revisited in May, 1986, to examine the extent of damage as well as changes in population density of G. toxicus and the toxicity of the benthic detritivore Ctenochaetus striatus. The toxicity of pooled livers of C. striatus is often used as an index of the ciguatoxicity of coral reef ecosystems (Yasumoto et al., 1984). G. toxicus population densities were determined by the method of Gillespie et al. (1985a). C. striatus were collected by spearing and the livers extracted using a standard procedure for assay of ciguatoxin (Lewis and Endean, 1984).

Slight damage to the coral of Sudbury Reef was noticed. Very little live hard coral was present, presumably as a result of previous Acanthaster planci infestations. A few larger dead coral boulders had apparently been dislodged and fallen from individual bommies. Soft coral dominated the available surfaces. There was no obvious change to that observed in October 1983.

In reporting G. toxicus population density the "highest value" rather than mean values has been used, principally because the sampling procedure which involves the sampling of only foliose macroalgae, is rather biased. Population densities found on Sudbury Reef in 1983 reach levels of 50 per gram but in May, 1986, were found not to exceed five per gram. Livers of C. striatus collected in May, 1986, were also only slightly toxic, each containing 0.12 M.U. (one mouse unit is the amount of toxin required to kill one 20 g mouse) or .08 M.U. per gram of liver.

In this case, it is apparent that cyclone Winifred would have had very little effect on ciguatera endemicity on Sudbury Reef, using G. toxicus populations densities and the toxicity of C. striatus livers as a guide. Previous studies by Bagnis (1969) have shown that up to 18 months after a disturbance may be required before ciguatoxin appears in the food chain. The situation following cyclone Winifred should therefore be monitored for up to two years, before clear conclusions can be drawn. More attention should also be given to reefs closer to the path of cyclone Winifred. The Department of Primary Industries will attempt to carry out this work as a part of its normal studies on the link between reef disturbance and ciguatera.

REFERENCES

Bagnis, R., 1969. Naissance et developpment d'une flambee de ciguatera dans un atoll des Tuamotu. Revue des Corps de Sante 10: 783-785.

Bagnis, R., 1981a. L'ichthyosarcotoxisme de type ciguatera: processus biologiques connus et perspectives au seuil des annees 80. Ann. Inst. Oceanogr. (Paris) 57: 5-24.

Bagnis, R., 1981b. L'ichthyosarcotoxisme de type ciguatera: phenomene complexe de biologie marine et humaine. Oceanol. Acta 4: 375-387.

Capra, M. and Cameron, J., 1985. Epidemiological and social surveys of the incidence of and the attitudes towards ciguatera poisoning in two Australian communities, in, Gabrie, C and Salvat, B., (Eds.) Proceedings of the Fifth International Coral Reef Congress, Tahiti, Volume 4, 489.

Gillespie, N.C., Holmes, M.J., Burke, J.B., and Doley, J., 1985a. Distribution and periodicity of Gambierdiscus toxicus in Queensland, Australia, In, Toxic Dinoflagellate Blooms. Elsevier, Holland.

Gillespie, N.C., Holmes, M.J., Burke, J.B. and Doley, J., 1985b. Effect of reef disturbance on macroalgal flora and populations of G. toxicus. Proceedings of the Australian Marine Science Asociation.

Hundloe, T. 1985. Fisheries of the Great Barrier Reef. Great Barrier Reef Marine Authority Special Publication Series, Number 2.

Lewis, R.J. and Endean, R., 1983. The occurrence of a ciguatoxin-like substance in the Spanish mackerel (Scomberomorus commersoni). Toxicon, 21: 19-24.

Lewis, R.J. and Endean R., 1984. Ciguatoxin from the flesh and viscera of the barracuda, Sphyraena jello. Toxicon,22:805-810.

Randall, J.E., 1958. A review of ciguatera, tropical fish poisoning, with a tentative explanation of its cause. Bulletin of Marine Science in the Caribbean Gulf. 8: 236-267.

Yasumoto, T., Nakajima, I., Bagnis, R. and Adachi, R., 1977. Finding of a dinoflagellate as a likely culprit of ciguatera. Bulletin of the Japanese Society of Science. 43: 1021-1026.

Yasumoto, T., Raj, U. and Bagnis, R., 1984. Seafood Poisonings in Tropical Regions, Laboratory of Food Hygiene, Faculty of Agriculture, Tohoku University.

EVALUATING TROPICAL CYCLONE WINIFRED, 1986 AS AN ENVIRONMENTAL THREAT.

John Oliver

THE EVENT

Cyclone Winifred crossed the North Queensland coast and ravaged the area north and south of Innisfail on February 1, 1986. The official forecast central pressure was 960 mb, although unofficial and uncorrected records for Flying Fish Point and for Croquet Point were respectively 952.4 mb and 956 mb. This would place the cyclone just in level 3 of the 5 level Saffir-Simpson hurricane intensity scale.

Many people in the affected area had held a view that cyclones tended to pass them by or crossed the coast well north. The last severe cyclone to affect the Innisfail area was in March 1918. This crossed the coast south of Cairns (Lourensz, 1981), and records show a central pressure 928 mb. The area suffered moderately badly when on March 6, 1956 a cyclone crossed the coast north of Townsville and moved inland on a north-west track. Memories of these earlier events had faded; older residents had died, and others had moved into the area.

The database is limited and often inaccurate. The earliest printed record (back to 1867) is sketchy, not always reliable and lacks firm data. The Bureau of Meteorology, using its own records and some of the early summaries, has published data from June 1909 to the present. (Lourensz, 1981: annual updates of the Australian Meteorological Magazine). To about 1960, there are probably omissions either of measured or interpolated values of central pressures, and even of cyclones that remained out at sea. Without cyclone reconnaissance aircraft, measured data for cyclones at sea are limited to chance information from ships caught in the storm (or nearer the coast from automatic weather stations on reefs or cays).

It is difficult, considering the length of coastline involved, to calculate probable return periods for cyclone occurrence, let alone differentiate the individual cases on an intensity basis. Table 1 shows the cyclones that crossed the coast (or came within 100 km of the coast with cyclonic intensity) between Thursday Island and Gladstone. Before 1954, no reliable pressure is available for many cyclones so the totals are probably too low.

Table 1. Cyclones crossing (sea to land or vice versa) or coming close to the coast. Thursday Island to Gladstone. Central pressure on crossing (mb); may have been lower at sea. 1909/10-1984/85 seasons.

Central Pressure	990-980 mb	980-960 mb	less than 960 mb
	18	10	4

Table 2. All cyclones crossing sectors of the coast (100 km) between 1909 and 1985.

Sector	Town within sector	Sea-land	Land-sea*
80	Mossman	11	4
81	Cairns	4	2
82	Innisfail	5	1
83	Ingham	2	4
84	Townsville	6	1
85	Bowen	2	1
86	Proserpine	4	3

*Note: Cyclones crossing from land to sea are generally less intense.

Generalisations about the potential impact of tropical cyclones are dangerous. No two cyclones behave identically even though they may have similar central pressures or even maximum, or mean wind velocities (further details about the structure and behaviour of cyclones may be found in Bureau of Meteorology, 1978, and in Oliver, 1985). As a consequence, evaluations of their environmental effects must be related to the particular case in question. It is this same diversity in characteristics or behaviour that makes their forecasting a difficult task. A number of the possible differences are briefly referred to below.

Differences between different cyclone prone regions

Although basically the same sort of physical system differences appear between the cyclones of the North Atlantic or north-west Pacific, or for that matter between north-west Australian, Gulf of Carpentaria and Coral Sea cyclones.

Cyclones as severe wind threats

Although there is a relationship between the central pressure and gust or mean, one or 10 minute wind velocities (10 m above surface) there is a considerable divergence in individual cases (perhaps 20 km/hr at 75 percent confidence) from indicative values.

There are other complications because the gust/mean value varies with the nature of the surface (roughness of the sea, or the nature of the terrain, vegetation, relief, buildings). Even surface temperature may affect the turbulence pattern.

Wind speeds are greatest in a ring of which the eye wall is the inner circumference. This maximum wind ring varies in width. Wind speed isopleths usually show asymmetries between different sides of the centre (often fastest on the left of the track).

Table 3. **Relationships between central pressure and wind speed.** The figures given are broad estimates only for one minute mean wind speeds.

Central pressure 990 to 980 mb :	100 to 130 km/hr
Central pressure 980 to 960 mb :	130 to 170 km/hr
Central pressure 960 to 940 mb :	170 to 220 km/hr

Cyclones as rain producers

There is little correlation between the central pressure and the total rainfall from a given cyclone. Some cyclones, though intense, yield relatively small totals (50 mm or less); others up to 300 mm. It is often their declining phase, when they can become "rain depressions", that the totals (especially where high ground is involved) can attain 800 to 900 mm (1 947 mm in the case of former cyclone Peter, as recorded at Bellenden Ker on January 4 and 5, 1979). Over the sea or small islands rainfall is usually lower. The rainfall tends, but not always, to be most to the left front of the cyclone. It may continue as heavy showers for some hours after the cyclone has passed.

The rate of passage of the cyclone, as well as rate of rainfall are significant factors. Over land, local convergence may add to local falls.

Cyclone storm tides

A rough and ready rule equates a pressure drop of 1 mb with a rise of 10 mm in sea level. The general sea level (or that around small islands) is little affected. The rise in sea level is greatly enhanced by the onward impulsion of the sea by the wind nearer land on the left of the track. Shallowing of the sea floor, coastal embayments, and the relationship between cyclone track and coastal orientation will all have varying and important effects. Particularly critical is the relationship between the pattern and timing regime and the arrival time of the surge. The generation of waves by the cyclonic winds adds a further complication which affects both the inundation level and the erosive energy of the waves.

The varying behaviour of the individual cyclone

Not only do different cyclones vary in behaviour, but so does an individual cyclone - its track varies, often erratically, in direction, while its speed of movement changes from being virtually static to a fast advance, possibly on more than one occasion. Rate of movement tends to be slower in the developing stage and increase as the cyclone becomes mature or declining. In many cases, the most destructive conditions last six to eight hours, but it can in some slow moving cyclones be much longer. The area affected by hurricane force (in excess of 117 km/hr) or gale force (greater than 63 km/hr) in different cyclones (or even in the same one) shows marked differences, although the central pressures may not differ. The shape of the area affected may well be asymmetrical, especially as the cyclone gets closer to land. The diameter of the eye is similarly variable and the duration of calm in a locality over which it passes will vary with the eye diameter and speed of cyclone travel.

CYCLONE WINIFRED

Cyclone Winifred demonstrated its own individuality.

It caused an abnormally wide band of wind damage north of its track to north of Cairns and on to the southern Atherton Tablelands. Over land, although building damage was considerable, the most dramatic effect of the wind was upon the rainforest and also on fruit trees, the banana crop, and some areas of sugar cane.

It was intense, but had a large eye (approximately 50 km in diameter over the sea) but the eye decreased rapidly as the cyclone moved inland declining to 22 km in diameter north of Tully, becoming diffuse by 60 km inland.

It showed varying rates of movement, being almost stationary for much of its earlier life, then advancing at varying rates (15 km/hr in the later stages up to landfall), showing small but difficult to interpret changes in direction until it quickly changed to a westward direction about mid-morning on February 1.

It was a significant rain producer. Many areas in the general Innisfail area received between 200 and 250 mm, and Cardstone, north of Tully, 400 mm. Rivers and creeks rose rapidly, especially the South and North Johnstone Rivers and the Herbert. Large amounts of sediment were carried out to sea.

Fortunately the surge coincided with low tide and coastal flooding and erosion was small.

Over the coastal areas, severe effects lasted about seven hours.

REFERENCES

Australian Meteorological Magazine. 1981, 1982, 1983, 1984, 1985. Bureau of Meteorology, Melbourne, Volumes 29-33.

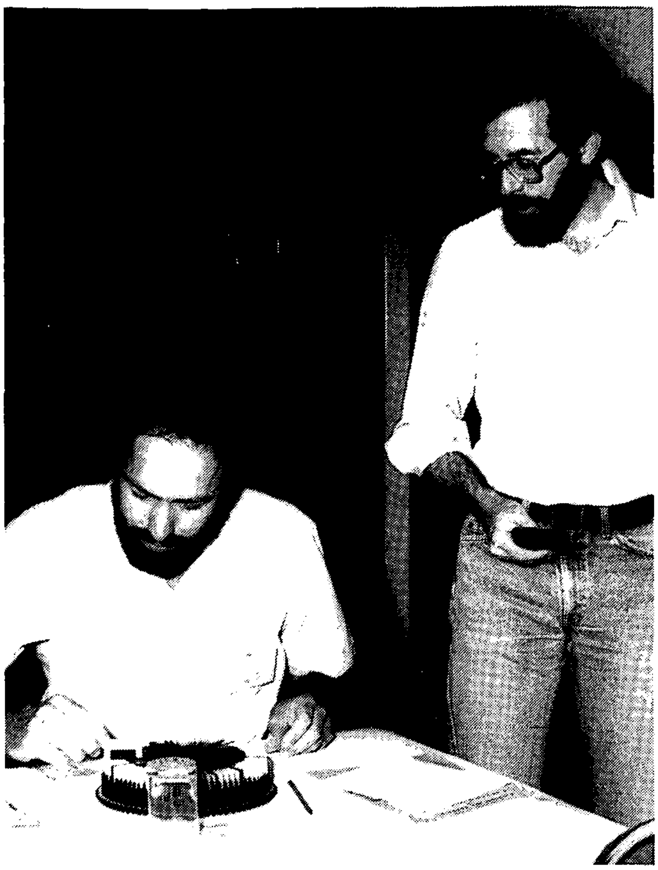
Bureau of Meteorology 1978. Australian Tropical Cyclone Forecasting Manual, Preliminary Edition, Bureau of Meteorology, Melbourne.

Lourensz, R.S. 1981. Tropical Cyclones in the Australian Region July 1909 to June 1980. Meteorological Summary, Bureau of Meteorology, Canberra.

Oliver, J. 1975. The Significance of Natural Hazards in a Developing Area: A Case Study from North Queensland, Geography, 60,2,99-110.

Oliver, J. 1978. Natural Hazard Response and Planning in Tropical Queensland, Natural Hazard Response Working Paper, Number 33, Institute of Behavioural Science, University of Colorado, Boulder, Colorado.

Oliver, J. 1985. The Nature and Problems of Tropical Cyclones in the Australian Region, Proceedings of the Ninth Invitation Symposium in Sydney, Australian Academy of Technological Sciences, Parkville, Victoria.



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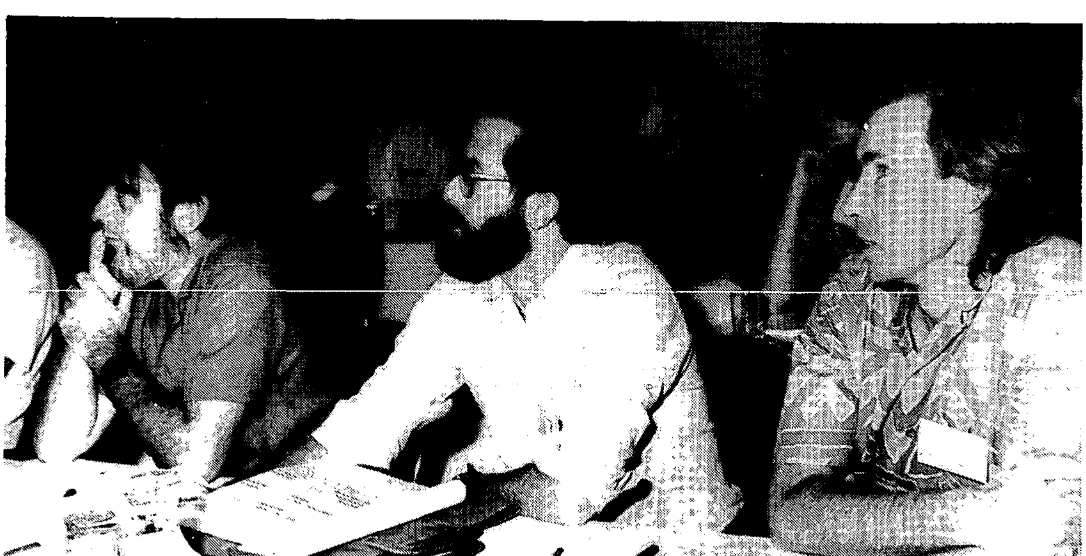


CYCLONE WINIFRED HITS NORTH QUEENSLAND*

Beach Protection Authority of Queensland

Cyclone 'Winifred' formed in the Coral Sea on January 29, 1986, and crossed the coast just south of Innisfail at about 7 p.m. on February 1, 1986. During this period the central pressure of the cyclone fell from 998 millibars to 958 millibars at the time of landfall. Maximum winds near the centre of the cyclone were estimated to be around 220 kilometres per hour.

The Beach Protection Authority operates a number of recording stations in the area affected by cyclone 'Winifred' and these include storm surge recorders at Cairns, Mourilyan, Clump Point, Cardwell and Lucinda. The cyclone tract was such that the peak surge associated with this cyclone was near the Clump Point storm surge recorder with lesser surges recorded at Mourilyan, Cardwell and Lucinda. Areas more remote from the point of landfall had only minor surges.

Data were obtained from the storm surge recorders at Clump Point, Cardwell and Lucinda during the cyclone using the telephone interrogation system attached to the recorders. Data accessed in this way provided the Bureau of Meteorology and the State Emergency Service with actual information during the cyclone for use in predicting maximum storm tide levels and formulating any necessary evacuation plans. Mr R. Lloyd, the Senior Engineer, Beach Protection, attended the State Emergency Service Headquarters during the period immediately prior to cyclone 'Winifred' crossing the coast to give expert advice on storm surge matters.

Fortunately, the cyclone crossed the coast at about the time of low tide and hence the resulting storm tide level was only about the same as a normal very high tide. However, the wave run-up from the high waves associated with the event washed over the frontal dune in most areas between Flying Fish Point and Tully Heads.

This exemplifies how north Queensland beaches with their low frontal dunes are vulnerable to storm tide inundation. Should the cyclone have crossed the coast at a time of a normal high tide, extensive areas would have been inundated and exposed to wave attack.

While minor beach erosion occurred along a number of beaches, significant erosion was restricted to the Kurrimine area where at one location a 2 metre high erosion scarp developed. The erosion in this area was accommodated by an underdeveloped buffer zone which has now been reduced to less than 20 m in places.

Beach Protection Authority officers inspected the affected areas soon after the cyclone to collect data and liaise with Local Authorities on matters relating to beach protection.

***This report is reprinted from Beach Conservation (63), May, 1986. The report is similar to that presented to the Workshop by Mr C. Witt.**

CYCLONE DAMAGE REPORT

HIDEAWAY TOURIST RESORT
Bedarra Island

"Hideaway" is a small resort situated on the western side of Bedarra Island. The resort is surrounded by rainforest and was therefore offered some protection from the full force of the cyclone. Effects upon the more exposed eastern and northern sides were, however more severe.

None of the buildings at the resort suffered much damage, with the exception of one unit that a large tree fell across, and water and sand that was carried into another unit closer to the beach. A tree also fell across, and destroyed the resorts' water tank.

Of the two boats which remained in the water during the cyclone, one (a 24' Huntsman) was sunk and the other (an 18' Sharkcat) dragged its mooring approximately 21 km but was later recovered.

The main damage was to the rainforest, with many trees and limbs being blown down and foliage stripped. The foliage that remained on the trees turned brown after a few days, presumably from wind or sunburn.

Guests departed from the resort the morning after the cyclone and the resort closed for two weeks to allow cleaning up operations and repairs to be carried out.

The regrowth of the rainforest is now quite vigorous, although it is still much thinner than normal, and some areas on the eastern and northern sides of the island are just starting to recover. Birdlife has apparently returned to its normal levels.

PACIFIC CLAM PTY. LTD.'S EXPERIENCE WITH CYCLONE WINIFRED

B. Marcum
Pacific Clam Pty. Ltd.

As concerns our experiences with an in-sea Giant Clam nursery, comprised of "Fabra Tanks" at Fitzroy Island, we suffered total loss to sea of all of our young clams on the last day of January, 1986.

Our "Fabra Tanks" did not break up, although some were damaged. Rather the temporary moorings broke away. One group of tanks was sighted passing Green Island, and the other group came away two days later. Our problem was that a single point, cyclone proof, mooring was designed, constructed, and paid for in Cairns, yet permission from the Cairns Port Authority to use this mooring was not received until 18 days after our loss.

We had winds of 50 knots from the south-east on the first day, of 94 knots from the south-east on the second day, and of 85 knots swinging from the north-east to the west on the third day.

This coming season we have plans that will allow us to firmly moor our tankage system to the bottom, in 3 to 5 m at high tide in an area of shallow reef, previously damaged by crown of thorns at Sudbury Reef.

REPORT ON FIELD TRIP TO TAYLOR, BEAVER, FARQUARSON AND EDDY REEFS - CAIRNS SECTION

J. Muldoon
Great Barrier Reef Marine Park Authority

On February 25 and 26, I undertook a field trip to the Mission Beach area. The aims of the trip were to look at the damage to some reefal areas from cyclone Winifred, to survey sites selected for the Quick Cat operation pontoon/semi-sub, and to manta-tow Beaver Reef to assess crown of thorns starfish damage, coral coverage and any scarring from crown of thorns.

After departing the Clump Point jetty at 0915 hrs, we proceeded to Taylor Reef and commenced to snorkel over a variety of potential sites for moorings. Of the four sites sampled, none seemed appropriate due to the absence of large areas of coral and the areas not offering the types of settings required for the viewing and glass-bottomed boat viewing. We then proceeded to Farquarson Reef where the situation was identical, with extensive bottom disturbance which had resulted in the overturning of bottom material with a lot of coral debris pushed into gutters and reef sides and banked up. Another result was that a large number of dead clams had been uncovered, giving the appearance of a high mortality rate in the area. The next reef to be assessed was Eddy Reef, which produced similar results.

On Wednesday, February 26, we were joined by Drs Zann and Craik, and Mr Kenchington for the trip to Beaver Reef and Cay.

CYCLONE DAMAGE REPORT - BEAVER REEF

Great Barrier Reef Marine Park Authority

On February 26, 1986 (25 days after cyclone Winifred), Beaver Reef was surveyed to evaluate cyclone damage, crown of thorns numbers, feeding scars, and coral cover.

Divers were manta-towed around the perimeter of Beaver Reef. A SCUBA inspection was undertaken on one shoal (south-western side of reef), but generally the extensive, deep shoals were not surveyed.

Standard GBRMPA manta-tow procedures were used, with the additional reporting of clams; two divers towed each 10 minute period. Weather was fine (5 to 10 knot winds) and visibility poor (about 6 to 10 m).

CYCLONE DAMAGE

Physical damage which can be attributed to the cyclone was only observed on one tow out of 13 (on approximately 100 m of easterly facing, shallow reef slope). Some evidence of broken coral, in the form of large broken staghorns, was reported. Generally there was no evidence of massive coral breakage or scouring, although rapid colonisation of surfaces by algae could have obliterated evidence of damage. Although the reef had a low level of live coral cover, largely due to crown of thorns starfish outbreaks, the survey team concluded that the reef and cay had not suffered significant physical damage from cyclone Winifred.

AFTER WINIFRED

J. Ranicar, OIC, JTTRE*
* Joint Tropical Trials and Research Establishment

Tropical cyclone Winifred, with destructive winds of up to 250 km/hr, crossed the Far North Queensland coastline at, or near, the Joint Tropical Trials and Research Establishment (JTTRE), Cowley Beach, early on Saturday evening, February 1, 1986.

The cyclone, which began gathering its forces out over the Coral Sea earlier in the week, caused immense damage to rainforests and communities between Babinda and Tully.

Cowley Beach instruments recorded a minimun barometric pressure of 957 mb at about 1715 hours, while JTTRE Pin Gin Hill measured 323.1 mm of rain during the passage of the cyclone.

Cyclone Winifred brought trees and power lines down throughout the district. Many houses were without water for 24 hours and most were without power for up to five days - with some waiting even longer.

JTTRE Cowley Beach was fortunate to have a large Australian Army team camped on-site for the Project RAVEN HF Radio Trials. The soldiers must be praised for the efficient and unselfish way they assisted with the massive clean-up operation, both at Cowley Beach and in the local community. However, with some 52 km of jungle tracks to clear at Cowley Beach alone, it may be years before the JTTRE environment fully recovers.

CYCLONE WINIFRED: AERIAL ASSESSMENT OF DAMAGE

I. Dutton
Great Barrier Reef Marine Park Authority
6 February 1986

Following discussions between GBRMPA, JCU, AIMS and Q.NPWS staff in the wake of cyclone Winifred, it was decided to organise a post cyclone damage assessment. Three common areas on interest were identified;

- effects on coastal and near coastal areas in the broad path of the cyclone where it crossed the coast (the area of most interest was identified as being between Hinchinbrook and Fitzroy Islands);
- effects on the Great Barrier Reef, offshore islands and structures; and
- river discharges - especially the extent and shape of plumes from rivers within the affected area.

Each agency has set in train actions to compile the information necessary for these assessments. Some of the activities underway include the following:

GBRMPA:

- organise surveillance flight;
- contact tourist operators to determine what damage (if any) sustained;
- design survey to assess impact on tourist perception (useful as basis for comparison with perception of crown of thorns phenomena);
- liaise with other agencies to secure relevant information from their field activities; and
- arrange for COASTWATCH assessment of offshore areas.

AIMS:

- organise field surveys of potentially affected reefs (many of which have only recently been surveyed as part of CEP/COT program); and
- determine impact on permanent research sites (mangrove areas at Hinchinbrook Island and in the Murray/Tully estuaries) by air survey.

JCU:

- determine extent of surge, tide and wave induced erosion of cays and coastline by field and air survey;

- field survey of effects on coastal structures;
- field survey of "how people coped" during and after cyclone; and
- locate and recover BMR barge with vibro-corer lost from Green Island.

Q.NPWS:

- assess fishing vessel wrecked on Brook Islands by air survey;
- assess damage to island and coastal National Parks by ground survey; and
- undertake surveillance flights of potentially affected areas in Cairns Section.

At a meeting on February 3, it was decided that many of the information requirements of each agency could be met (initially at least) by an aerial reconaissance of the impacted area. This was organised to proceed on the afternoon of February 4. However, due to problems with the chartered aircraft, an alternative charter was organised for the following day. Participants included:

Mr D. Savage (Q.NPWS)
Mr T. Done (AIMS)
Dr T. Smith (AIMS)
Ass. Prof. D. Hopley (JCU)
Dr L. Zann (GBRMPA)
Mr I. Dutton (GBRMPA)

The flight consisted of a three hour circuit from Townsville along the coast to Fitzroy Island, returning via the outer reef. A complete slide and photo sequence of flight observations was lodged in the Authroity's collection.

The most significant observations from the flight were:

- There appears to be little damage to coastal mangrove communities, although extensive areas of island and coastal forest have been defoliated (their appearance is similar to a post-bushfire landscape).
- There appears to be little damage to island cays and reefs. D. Hopley (who has 20 years of experience with this area) noted no perceptible change in the morphology or appearance of exposed features, and little apparent change in subsurface features, although visibility around some reefs is poor. There was no evidence of large scale coral collapse and no new "blocks" appear to have been thrown onto the reef flat. A ground survey will be essential to determine more localised impacts.
- Most tourism infrastructure appears to have survived intact. Some damage was observed to buidlings on Dunk and Bedarra Islands and at Mission Beach. Ground surveys and reports from individual operators are necessary to determine the extent of damage.

- There was no sign of the floating raft system used for giant clam mariculture at Fitzroy Island. Contact will need to be made with B. Marcum to establish whether damage occurred.

- River plumes from the Herbert, Murray, Tully, Hull, Johnstone and Mulgrave/Russell Rivers and major creeks (notably Maria Creek which drains the area where the cyclone crossed the coast), were very obvious and extensive in terms of their area of influence. For example the Herbert River plume extended to the northern end of the Palm Group; the Mulgrave/Russell around the Frankland Islands. Restrictions on flying time limited the extent to which the plumes could be tracked. It was decided that it would be very useful to obtain LANDSAT imagery (a pass will occur on 7/2/86) for tracking purposes.

RECOMMENDATIONS

Despite the apparent lack of broadscale damage to the Great Barrier Reef, it would appear desirable to arrange for the following assessment activities:

- Ground survey of selected reefs in cyclone path. This can be done in concert with AIMS who have arranged for a preliminary assessment on February 7 and 8. Mr McClymont (GBRMPA) will participate. Depending on the results of that survey, provision may need to be made for ongoing monitoring and/or follow up studies (a more comprehensive survey is planned for about Februaury 25 and 26; Authority staff have been invited to participate).

- Collation of offshore infrastructure damage reports. Preliminary advice from one operator indicates mooring damage. This information is important to management of many types of offshore developments and could provide valuable guidance on future proposals and management of existing facilities.

- Continue liaison with other agencies on their assessment activities and provide support as appropriate. For example, a request has been received to contribute to a JCU study of the effects on benthic communities. This is currently under consideration.

- Ongoing studies of the extent of terrestrial influence on the Great Barrier Reef and lagoon through Research and Monitoring programs. This could be integrated with the proposed COTSAC study "Relationships between *Acanthaster* outbreaks and Water Mass Characteristics of the GBR" (GBRMPA). The cyclone (during the presumed *Acanthaster* planktonic season) represents an ideal opportunity to test Birkeland's hypothseis.

- Provide for funding of research on the effects of cyclones on tourist perception of Great Barrier Reef (additional to proposed project on effect of the *Acanthaster* phenomena on tourist perception).

- Contribute to the organisation of a small workshop reviewing cyclone Winifred and its impacts. The workshop could include short reports from involved agencies on the findings of their studies and their implications for management of the Great Barrier Reef and response to future incidents.

ANNOTATED BIBLIOGRAPHY ON CYCLONES WITH PARTICULAR REFERENCE TO CORAL REEFS

J. DARTNALL
Great Barrier Reef Marine Park Authority

This bibliography is not intended to be comprehensive but to indicate some key references and some areas of relevant research. Works have been described mainly from the viewpoint of their contribution to information on offshore cyclone effects.

BACKGROUND TO CYCLONES

LOURENSZ, R.S. Tropical cyclones in the Australian Region July 1909 to June 1980. Canberra, AGPS, 1981. 94 pages.

> This report contains basic meteorological data for Australian region cyclones for the period for which the Bureau of Meteorology holds records. The data includes chronological lists with central pressures and directions at landfall, charts showing cyclone tracks and information about speed, direction and incidence of cyclones displayed in a number of ways. [Compiler's note: annual tropical cyclone summaries are prepared by the Bureau of Meteorology and can be used to update this report.]

AUSTRALIA. DEPARTMENT OF SCIENCE. BUREAU OF METEOROLOGY. Report on Cyclone Tracy, December, 1974. Canberra, AGPS, 1977. 81 pages.

> This report is a summary of information about the small but intense cyclone, Tracy. The emphasis is on meteorological data revealed by direct radar and satellite observation and on an assessment of the effectiveness of the cyclone forecasting system. There is no direct information on offshore effects of the cyclone. [Compiler's note: Reports of this type are prepared for most major Australian cyclones.]

ANTHES, Richard A. Tropical cyclones; their evolution, structure and effects. Boston, American Meteorological Society, 1982. 208 pages.

> This book is particularly concerned with the physical processes that create and sustain cyclones. It also deals with numerical modelling of cyclones, forecasting and hurricane modification. There is a chapter on oceanic responses to tropical cyclones. Here the author explores the theoretical background to observations that sea surface temperatures may be decreased by 6°C following the passage of a cyclone and that mean sea level under a storm is raised about 10 mm for each millibar of pressure drop. The extent of upwelling and downwelling caused by cyclonic storms is also considered.

AUSTRALIA. DEPARTMENT OF SCIENCE. BUREAU OF METEOROLOGY. Regional tropical cyclone seminar, Brisbane, May, 1973. Canberra, AGPS, 1973. 224 pages.

The papers in this seminar proceedings explore cyclones from many viewpoints. Some emphasis is placed on the economic, social and psychological impacts of tropical cyclones and how forecasting and warning is undertaken and might be improved. There is no direct coverage of offshore cyclone effects.

SIMPSON, Robert H. : RIEHL, Herbert. The hurricane and its impact. Baton Rouge, Louisiana State University Press, 1981. 398 pages.

The preface to this book states that it is intended for undergraduates and as a reference work for technical users such as architects, engineers and building contractors. The book includes a physical description of hurricanes and an analysis of hurricane effects on coasts, waves and tides. The final section "Planning Co-existence with the Hurricane Hazard", discusses hurricane awareness and preparedness, prediction and warning and looks at the various methods that have been investigated for direct reduction of hurricane force.

REPORTS EMPHASISING GEOMORPHOLOGY

MOORHOUSE, F.W. The cyclone of 1934 and its effects on Low Isles, with special observations on Porites. Reports of the Great Barrier Reef Committee 4 (3) : 37-44, 1936.

This report starts with an account of the author's personal experience of the 1934 cyclone. Immediately after the cyclone extensive damage was observed on the island and reef flat. Much of the later damage had been caused by smothering due to shingle having been carried 25 to 30 yards over the flat. These major geomorphological changes produced changes in water depth in moated areas of the reef flat. The effect of consequent increased exposure on Porites in some areas was not evident for some months.

HERNANDEZ-AVILA, M.L. : ROBERTS, Harry H. : ROUSE, Lawrence J. Hurricane-generated waves and coastal boulder rampart formation. Proceedings. Third International Coral Reef Symposium 2 : 71-78, 1977.

This paper considers theoretically the energy of hurricane wave forces required to destroy stony corals and produce coral rubble ramparts. The rampart on Grand Cayman Island was used as an example. The authors conclude that known hurricane forces are sufficient to destroy stony corals at a depth of 12 m. They note that laboratory and field experiments indicate that the breaking strength of a stony Acropora species depends considerably on the degree to which the skeleton has been weakened by boring organisms.

BAINES, G.B.K. : BEVERIDGE, P.J. Storms and island building at Funafuti Atoll, Ellice Islands. Proceedings of the Second International Coral Reef Symposium 2 : 485-496, 1974.

In October 1972, hurricane Bebe deposited on Funafuti Atoll a storm beach of coral rubble about 19 km in length and up to 4 m in height. This paper records a number of observations of this beach. Underwater observations on the reef slope failed to find corals in depths shallower than 15 to 20 m. The slope to this depth was covered with rubble similar to that forming the storm beach. From this and other evidence the authors conclude that the storm beach material was of submarine origin. The authors consider that "the formation of massive storm beaches, while infrequent, could lead to a seaward prograding of motus and might ...account for the seaward sequence of ramparts seen in some localities."

FAIRBRIDGE, Rhodes W. : TEICHERT, Curt. The Low Isles of the Great Barrier Reef : a new analysis. Geographical Journal 111 : 67-88, 1948.

The paper reports a survey undertaken in 1945 which noted changes consequent on the 1934 cyclone. This cyclone had done considerable damage to the moat system of the reef platform and this damage was still evident in 1948.

STODDART, D.R. Effects of Hurricane Hattie on the British Honduras Reefs and Cays, October 30-31, 1961. Atoll Research Bulletin (95), 1963. 142 pages.

A major geomorphological study of the British Honduras reefs and cays had been completed about three months before hurricane Hattie. This report gives a brief description of the area, an account of Hurricane Hattie and a description of the immediate effects of the hurricane on cays, reefs, vegetation and the people of the region. The author recognised a series of zones of damage with maximum damage extending 15 to 20 miles on either side of the hurricane track. Within this zone a number of small cays disappeared completely and all were subject to major changes including loss of large plants and of surface sand. A zone approximately 15 miles wide on either side of this experienced tree fall and minor erosion. A zone of more limited damage was identified beyond these. Underwater damage mirrored this situation, there being maximum coral damage in the first zone where about 80 percent of reef coral had disappeared. There was some evidence that cays which had been cleared for coconut plantations suffered more damage than those with natural vegetation.

STODDART, D.R. Post-hurricane changes on the British Honduras Reefs and Cays : re-survey of 1965. Atoll Research Bulletin (131), 1969. 25 pages.

This paper reports a re-survey of the area described in the previous citation. The author could still identify the zones of damage observed soon after the hurricane and considered that regeneration of coral had not occurred in the zone of maximum damage. Further erosion was observed on cays damaged by the hurricane and the author considered that some of these might subsequently disappear. Revegetation had occurred on many cays although some mangroves defoliated during the hurricane had later died and intertidal areas were still bare of larger algae.

HOPLEY, David. Coastal changes produced by tropical cyclone Althea in Queensland : December 1971. Australian Geographer 12 (5) : 445-456, 1974.

This paper is a detailed account of the geomorphological changes produced by cyclone Althea. It considers separately the changes observed on sandy coasts, mangrove coasts, coral shingle coasts and on reefs. Severe erosion (in some cases exceeding 15 m of recession) was noted on sandy coasts and also on coral shingle coasts while the mangrove areas proved remarkably resilient. The limited observations of reefs suggested that little damage had been sustained.

HOPLEY, David : ISDALE, Peter. Coral micro-atolls, tropical cyclones and reef flat morphology : a North Queensland example. Search 8 (3) : 79-81, 1977.

By exploring the geomorphology of the micro-atolls of Holbourne Island, the authors identified changes consequent upon coral death caused by the cyclone of 1918. Breaching of the rampart during that cyclone is presumed to have drained a moat previously supporting coral growth above normal sea level. Following the cyclone further growth of coral had occurred only in those reef flat areas protected by other ramparts.

DAVIES, Peter J. : HUGHES, Howard. High-energy reef and terrigenous sedimentation, Boulder Reef, Great Barrier Reef. BMR Journal of Australian Geology and Geophysics 8 (3) : 201-209, 1983.

This paper reports on water movement patterns and sediment flux at Boulder Reef before, during and after the passage of cyclone Dominic in April 1982. Terrestrially derived sediment reached the Reef in two pulses, one and five days after the passage of the cyclone. The authors conclude that "...clay is getting out to the inner-shelf reefs close to and north of Cooktown, every five years or so and in amounts within the range of 135 to 228 tonnes. Such events would have occurred one thousand times since sea level stablised in eastern Australia."

PRINGLE, Ada W. Sand spit and bar development along the east Burdekin delta coast, Queensland, Australia. James Cook University of North Queensland, Department of Geography Monograph Series No. 12, 1983. 34 pages.

This study investigates in detail the development of the most rapidly changing section of the east coast of the Burdekin delta. The main tool used in the study is aerial photography surveys undertaken between 1942 and 1980. Among the factors found to influence sediment supply, and hence changes in coastal shape are floods, mangrove colonisation and cyclones. The movement of sediment along the coast is effected by wave and water current action mainly under the control of the south east trade winds. However cyclones may produce large waves and surge effects from unusual directions and reverse normal trends.

KJERFVE, Bjorn and others. Hindcasting of hurricane characteristics and observed storm damage on a fringing reef,

Jamaica, West Indies. Journal of Marine Research 44 : 119-148, 1986.

This paper presents a mathematical model for assessing wave heights and power and water velocity during cyclone Allen (1980). The authors note that the most conspicuous effect of Allen at Discovery Bay was the breaking of many corals, especially branching forms. This breakage, and the subsequent predation and disease, reduced acroporid coral populations to 2 percent of pre-hurricane levels. The authors speculate that the degree of damage evident on a reef is a function of time since the last storm rather than average frequency of storms at a locality.

REPORTS EMPHASISING BIOLOGICAL OBSERVATIONS

RANDALL, Richard H. : ELDREDGE, Lucius G. Effects of typhoon Pamela on the coral reefs of Guam. Proceedings. Third International Coral Reef Symposium 2 : 525-531, 1977.

Historical records suggest that Guam is likely to experience a significant typhoon on average every seven years. Typhoon Pamela crossed Guam in May 1976. Least disturbance was recorded on rocky shores and those protected by barrier reefs and most on shores of unconsolidated sediments. The authors noted suprisingly little reef damage in contrast to major damage to coastal vegetation and changes in beach morphology. They noted that the outer reef margin experienced more damage than submerged reef flat and that breaking of branches from branched corals was the most frequent form of damage. Individual coral colonies with broken branches were noted to a depth of 30 m.

JIMENEZ, Jorge A. : LUGO, Ariel E. Tree mortality in mangrove forests. Biotropica 17 (3) : 177-185, 1985.

This paper reviews causes of massive mangrove tree mortality. A list of reported mortalities due to cyclones and hurricanes is given. The authors conclude that such mortality is not catastrophic in the sense that the mangrove forests cannot regenerate. The situation can be rendered catastrophic if human interference causes environmental changes preventing forest regeneration.

STEPHENSON, W. : ENDEAN, R. : BENNETT, Isobel. An ecological survey of the marine fauna of Low Isles, Queensland. Australian Journal of Marine and Freshwater Research 9 (2) : 261-318, 1958.

The paper reports a survey undertaken in 1954 to assess the extent and nature of changes following a cyclone of moderate intensity over the Low Isles in 1950. Attempts were made to compare observations with those made by the 1928-9 Great Barrier Reef Expedition. Most of the damage caused by this cyclone seems to have been due to the mechanical effects of breaking waves which struck what is normally the lee side of the islands. Delicate and branching corals were extensively damaged while more massive species survived. The authors suggest that mobile coral rubble produced by the cyclone hampered recolonisation by hard corals while soft corals, which had not been damaged by the cyclone, were competing for substrate.

LANGHAM, N. The effect of cyclone 'Simon' on terns nesting on One Tree Island, Great Barrier Reef, Australia. Emu 86 (1) : 53-57, 1986.

Cyclone Simon produced strong winds and heavy rain on One Tree Island during February 1980. During the cyclone, adult birds with fledged chicks disappeared from the island. There was a marked difference in chick mortality between tern species with much loss among white-capped noddies and crested terns but little in the bridled tern chicks. Chicks of all three species lost weight during the cyclone because parent birds could not forage.

HEINSOHN, George E. : SPAIN, Alister V. Effects of a tropical cyclone on littoral and sub-littoral biotic communities and on a population of dugongs (Dugong dugong [Muller]). Biological Conservation 6 (2) : 143-152, 1974.

This paper describes the effects of cyclone Althea, 1971. Immediate effects on mangrove areas were limited although longer term damage resulting from shifted sand clogging tidal channels was noted. It is stated that severe wave action caused considerable coral damage, decreasing with water depth but still observable at 7 m. Increased numbers of dugong were caught in shark nets following the cyclone. It is considered that this was a consequence of increased dugong movement in search of food following destruction of seagrass beds. Changes in stomach contents of dugongs caught before and after the cyclone support this.

WOODLEY, J.D. and others. Hurricane Allen's impact on Jamaican coral reefs. Science 214 (4522), 749-754, 1981.

This paper describes the immediate impact of hurricane Allen, the strongest Caribbean hurricane of this century, on the previously well studied coral reef communities of Discovery Bay, Jamaica. Physical disturbances extended to a depth of 30 m and damage was caused not only by violently moving water but also by dislodged solid objects. Among the interesting observations made were the spatial patchiness of damage and changes in fish behaviour immediately following the hurricane.

PEARSON, R.G. Recovery and recolonization of coral reefs. Marine Ecology : Progress Series 4 (1) : 105-122, 1981.

This paper reviews published reports on recovery of coral reefs after damage by a wide range of natural and man-made disturbances. One section discusses recovery following cyclones and attempts to explain the widely different situations reported in the literature. There is also a discussion of factors that might influence recovery and recolonisation including extent and location of damage, the availability of coral larvae, the presence of grazers to inhibit the competitive growth of algae and the range of microhabitats available for coral settlement.

WOODHEAD, P.M.J. Surveys of coral recolonization on reefs damaged by starfish and by a cyclone. Studies in Biology from Memorial University of Newfoundland No. 261. (Reprinted as Appendix E in "Report of the Committee appointed by the

Commonwealth and Queensland Governments on the Problem of the Crown-of-thorns Starfish (Acanthaster planci)", 1971, p.34-40.)

This paper reports a survey of Heron Reef 3.5 years after severe damage to the reef by cyclone Dinah in January 1967. The results are compared with recolonisation of Green Island Reef and Feather Reef following Acanthaster infestations. Twenty-seven genera and subgenera of corals were seen on Heron Reef and the author concludes that "...it seems probable that the damaged slopes of the reef will be recolonized by well-grown colonies of corals 10 years after the cyclone."

STODDART, D.R. Huricane effects on coral reefs : conclusion. Proceedings of the Fifth International Coral Reef Congress, Tahiti 3, 349-350, 1985. [Compiler's note: This conclusion follows five papers on aspects of hurricanes presented at the Congress.]

The author notes that there is now a considerable body of descriptive work on the effects of hurricanes and that physical components of storm systems such as pressure, wind speed and direction, wave action and storm surge can be successfully predicted. He suggests that areas of future investigation that need to be explored include more fundamental questions such as comparison with reefs not subject to hurricanes; a systematic exploration of the relative importance of slow growing and fast growing corals in reef structure and assessments of what constitutes equilibrium in coral reef communities.

REPORTS EMPHASISING SOCIO-ECONOMIC OBSERVATIONS

SOUTHERN, R.L. Utilization of tropical cyclone warning : can man respond to scientific progress in Natural Hazards in Australia edited by R.C. Heath and B.G. Thom. Australian Academy of Science, 1979, p.392-405.

The author points out that although cyclone warning systems are becoming more effective because of technological improvements their benefits depend upon human ability to use the information provided. The author is pessimistic about progress in community preparedness and application of mitigation measures. He considers that "In the long term mitigation measures and land use controls, although costly or unpopular, will do most to reduce the impact of rare but potentially devastating cyclones".

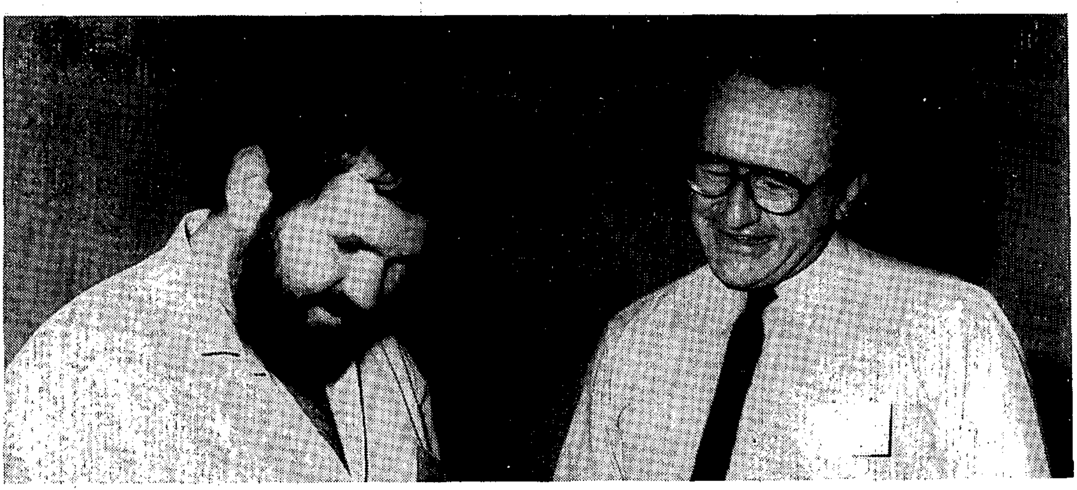
CHAMBERLAIN, E.R. and others. The experience of Cyclone Tracy, Canberra, AGPS, 1981. 191 pages.

This book reports research undertaken by the Social Welfare Commission and the Commonwealth Department of Social Security on the stress experienced by Darwin residents following Cyclone Tracy. The authors conclude that disruption of the familiar and valued environment, both physical and, more importantly, social aspects of this environment, was the major cause of stress. They note the well documented importance of family and friends in helping affected people cope with a natural disaster. The work documents the variety of personal and family problems experienced by the cyclone survivors. These include financial problems, practical problems such as accommodation and schooling and emotional problems ranging from loneliness to serious nervous disorders.

WESTERN, J.F. : DOUBE, L. : Stress and Cyclone Tracy in Natural Hazard Management in North Australia. Edited by G. Pickup, North Australia Research Unit, 1978, p375-401.

This is a paper preliminary to the previous reference and deals in particular with differences in stress effects between those residents who remained in Darwin after the cyclone and those who were evacuated. The latter group exhibited, in general, more stress related problems.

Appendices



APPENDIX I: WORKSHOP PARTICIPANTS

NAME	AFFILIATION	GROUP*
Mr G. Andrews	James Cook University	1
Mr R. Bell	James Cook University	1
Mr A. Birtles	James Cook University	1
Mr G. Blackman	Q.NPWS	2
Dr L. Bode	James Cook University	4
Dr R. Bradbury	AIMS	-
Mr R. Braley	Seafarm/ James Cook University	2
Mr G. Buden	Bedarra Island	-
Mr D. Carr	James Cook University	2
Prof. R. Carter	James Cook University	2
Dr W. Craik	GBRMPA	4
Mr G. Crane	Bureau of Meteorology	4
Dr A. Dartnall	AIMS	3
Mr L. de Vantier	AIMS	1
Mr G. Deane	Premier's Department, Qld.	3
Ms S. Driml	GBRMPA	3
Dr T. Done	AIMS	1
Mr I. Dutton	GBRMPA	2
Ms J. Dye	James Cook University	1
Maj. M. Evans	Royal Australian Army	-
Mr D. Fisk	Consultant	1
Dr M. Furnas	AIMS	1
Dr P. Foley	James Cook University	3
Mr M. Gagen	James Cook University	1
Dr M. Gourlay	University of Queensland	4
Dr M. Heron	James Cook University	1
Mr W. Higgins	Johnstone Shire Council	4
Dr T. Hundloe	Griffith University	3
Ass. Prof. D. Hopley	James Cook University	2
Mr R. Hughes	Q.NPWS	3
Prof. R. Jackson	James Cook University	3
Mr R. Jaycock	Bureau of Meteorology	1
Dr D. Johnson	James Cook University	2
Mr G. Kelleher	Chairman, GBRMPA	-
Dr D. Kinsey	GBRMPA	1
Dr R. Lewis	Qld Department of Primary Industries	2
Mr B. Jahuad	Cameron McNamara Pty. Ltd.	-
Mr K. McClymont	GBRMPA	1
Mr B. Miller-Smith	GBRMPA	1
Mr F. Muir	Q.NPWS	1
Cr. J. O'Brien	Johnstone Shire Council	3
Prof. J. Oliver	ex James Cook University/NDO	3
Mr M. Riddle	AIMS	1
Dr M. Sandstrom	AIMS	1
Ms M. Shannon	NQCC	3
Dr T. Smith III	AIMS	1
Prof. K. Stark	James Cook University	4
Mr C. Tilley	GBRMPA	4
Mr M. Tenni	SES - Townsville	4
Dr T. Thorpe	James Cook University	-
Ms V. Tzoumis	James Cook University	1
Ass. Prof. G. Walker	James Cook University	4
Mr R. Whittle	Townsville City Council	-
Mr C. Witt	Beach Protection Authority	2
Dr E. Wolanski	AIMS	1
Dr L. Zann	GBRMPA	1

*Group 1 -	Biophysical and Ecological Aspects: Chairman - L. Zann, Rapporteur - B. Miller-Smith
Group 2 -	Biophysical and Ecological Aspects: Chairman - D. Hopley, Rapporteur - I. Dutton
Group 3 -	Socio-economic/Attitudinal Aspects: Chairman - J. Oliver, Rapporteur - S. Driml
Group 4 -	Socio-economic/Engineering Aspects: Chairman - K. Stark, Rapporteur - W. Craik

APPENDIX II: WORKSHOP PROGRAM

TIME	TOPIC	SPEAKER
0900	INTRODUCTION	**Dr D. Kinsey** (GBRMPA)
0905	The potential significance of cyclonic events to management of the Great Barrier Reef Marine Park.	**Mr G. Kelleher** (G)
0915	The meteorology of cyclone Winifred.	**Mr G. Crane** (Bureau of Meteorology)
0930	Wind speeds and structural behaviour in cyclone Winifred.	**Ass. Prof. G. Walker** (JCU)
0945	Reports of individual experience.	**Mr K. McClymont (G)** **Mr F. Muir** (Q.NPWS) **Dr R. Lewis** (DPI) **Prof. J. Oliver** **Mr C. Witt** (BPA)
1015	**MORNING TEA**	
1035	Oceanographic conditions of the North Queensland shelf after the passage of cyclone Winifred.	**Dr M. Furnas** (AIMS)
1045	Some comparisons between the observed and modelled oceanographic response to tropical cyclone Winifred.	**Dr L. Bode** (JCU) **Dr E. Wolanski** (AIMS)
1055	Sediment redistribution on the Great Barrier Reef shelf by cyclone Winifred (Parts 1 and 2).	**Dr D. Johnson <u>et</u> <u>al</u>.** (JCU)
1110	The bio-geochemical effect of cyclone Winifred.	**Dr M. Sandstrom** (AIMS)
1120	Some preliminary observations from a survey of the soft sediment biota of the inner and middle shelf of the Great Barrier Reef following cyclone Winifred.	**Mr A. Birtles** (JCU)
1130	An overview of the geomorphic and ecological effects.	**Dr T. Done** (AIMS)
1140	The effects of cyclone Winifred on corals at Green Island reef.	Mr D. Fisk (JCU)
1150	Comparitive effects of cyclone damage to mangrove forests: Kathy versus Winifred.	**Dr T. Smith III** (AIMS)
1200	Effects of cyclone Winifred on coastal and island fauna.	**Mr G. Blackman** (Q.NPWS)

1210 Environmental loss - the hidden aspect of post-natural disaster phychological distress.
Mr P. Foley (JCU)
Dr R. Thorpe (JCU)

1230 **LUNCH**

1330 The perspectives and commitments of the Australian Institute of Marine Science to cyclone research.
Dr R. Bradbury (AIMS)

1340 SMALL GROUP DISCUSSIONS - refer to Appendices I and III.

1525 **AFTERNOON TEA**

1555 GROUP REPORTS

1625 SUMMING UP

1640 CLOSE
Dr W. Craik (GBRMPA)

APPENDIX III: BRIEF FOR SMALL GROUP DISCUSSIONS

Two 'pairs' of small discussion groups have been defined. the participants , in each group are presented in the list of participants (Appendix I).

Groups 1 and 2 will address the biophysical aspects of cyclone Winifred, while Groups 3 and 4 will address the social, economic, and engineering aspects of the cyclone.

GROUPS 1 AND 2

DISCUSSION OBJECTIVE:
To assess the biophysical significance of cyclone Winifred, and how it may affect our understanding of the Great Barrier Reef system.

DISCUSSION TOPICS:

- Was Winifred a significant event compared with other natural phenomena which influence the GBR?
- How did Winifred affect our understanding of the Great Barrier Reef system and its constituent ecological patterns and processes?
- How can the scientific information obtained be applied to the management of the Great Barrier Reef Marine Park?
- Were the scientific response and studies undertaken adequate? If not, in what respects were they inadequate?
- What longer term and/or follow-up studies are necessary or desirable?

Note: Any additional topics of relevance may be considered when the above have been discussed.

GROUPS 3 AND 4

DISCUSSION OBJECTIVE:
To assess the socio-economic (including engineering) significance of cyclone Winifred, and how it may affect the use of the Great Barrier Reef Region.

DISCUSSION TOPICS:

- Was Winifred a significant event in terms of human use of the GBR in comparison with other natural phenomena which influence human use?
- How did Winifred affect human use of the GBR?
- How did Winifred influence future use of the GBR (for example, engineering design standards, spatial patterns of human use, tourist perception of hazard)?
- How can the the socio-economic information obtained be applied to the management of the Great Barrier Reef Marine Park.

- Was the scientific response adequate, in investigating the socio-economic aspects? If not, in what respects was it inadequate?

- What longer term and/or follow-up studies are necessary or desirable?

Note: Any additional topics of relevance may be considered when the above have been discussed.