2. HISTORY OF RESEARCH AND MONITORING OF CYCLONES AND FLOOD PLUMES IN THE GREAT BARRIER REEF

Cyclones are the most important natural agents of disturbance on coral reefs in non-equatorial regions (Done 1992). Cyclones can affect the community composition of reef corals and thus on coral reef structure, both directly and through its influence on biological interactions. Both direct effects such as cyclone generated waves, and indirect effects such as turbid, sediment laden river plumes can substantially alter the physical structure and community composition of reefs (Puotinen et al. 1997; Done 1992; Done et al. 1991; Woodley et al. 1981). Direct effects may include the removal of the reef matrix via scouring and fragmentation (Van Woesik et al. 1991) and both direct and indirect structural damage from breaking waves and wave-borne debris (Done et al. 1991). Decline in salinities may cause coral bleaching and mortality of shallow reef corals (Brodie et al. 1997; Devantier et al. 1997; Van Woesik et al. 1995; Rainford 1925).

Research reviewed in this chapter has been mostly directed at sampling post-cyclone impacts and water quality conditions in the aftermath of large cyclone-related flood plumes. However other work has focused more on the damage to the benthic communities and mechanical movement of plumes and sediments rather than the water quality conditions of the flood plume and physio-chemical changes in the water column. Table 2 summarises cyclone characteristics and sampling undertaken for selected cyclonic events in the GBR from 1918 to 1988.

Early observations were made by Orr (1933) of the presence of flood plumes around Low Isles in February 1929 where he noted that the adjacent Daintree River was in flood. Widespread loss of coral cover in the Whitsunday area associated with the major floods of January 1918 (the 'Mackay' cyclone) in the Whitsunday's area, was reported by Rainford (1925) and Hedley (1925). Anecdotal accounts of freshwater at the surface eight miles offshore were also recorded. The probable effects of wind direction on plume dispersion were noted at this time. Pickard et al. (1977) noted that the bulk of river run-off occurs during a few short-lived floods.

High concentrations of dissolved nutrients were recorded off Townsville and in Bowling Green Bay, up to 50 km north of the Burdekin River mouth for periods of two or more weeks during the 1977–78 wet season (Revelante & Gilmartin 1982) and following cyclone Charlie in 1988 (Liston 1990). These concentrations decreased as a result of uptake by local phytoplankton and zooplankton populations, which developed a pronounced bloom in response to the increase in available nutrients. On Boulder Reef, off Cooktown, Davies and Hughes (1983) found elevated levels of suspended sediments during cyclone Dominic, which they surmised, were derived from the transport of terrigenous clays from the flood plumes of the Endeavour River.

Burdekin River plumes in the flood events of 1980 and 1981 (Wolanski & van Senden 1983; Wolanski & Jones 1981) resulted in lowered salinity from the mouth of the river north to Cairns and 40 km across the GBR lagoon.

Cyclone Winifred (1 February 1986) was a severe tropical cyclone with maximum wind gusts of 198 km/hr (Gagan et al. 1987) that crossed the coast south of the Johnstone River. It caused heavy rainfall and near record flooding (5715 m^3/s) of the Johnstone River. The resultant large freshwater plume from Winifred caused reductions in shelf waters with measured salinities ranging from 10 to about 35. Geographic influence of the bio-physical impacts of Winifred was largely restricted to areas between Cooktown and Cairns. Short-

term, extreme changes were noted to be increased turbidity, nutrient resuspension and changes in current patterns (Done et al. 1986). Long-term changes were related to plant and animal succession (Furnas & Mitchell 1986). Water quality sampling following Winifred showed concentrations of inorganic nitrogen species were readily detectable and often quite high (> 1 µM) with chlorophyll concentrations up to 18 µg/L (Furnas 1989).

Table 2. History of cyclones and significant flood events in the Great Barrier Reef and their biological impacts

Year	Cyclone	Duration of Flooding	'Rivers'	Wind Speed/ Direction	Sampling Dates/Areas	Observed Effects
1918	'Mackay'	22/1/18–29/1/18	Pioneer Don Burdekin	Lowest pressure recorded was 933hPa	'Observations' at Port Denison 3.6 m storm surge into Mackay	Storm surge: 4 m Freshwater at sea (8 miles from land) Loss of coral cover on Stoney Reef (Hedley 1925; Rainford 1925)
1932			Daintree			Low Isles (Orr 1933)
1934		12/3/34		SE-NE	Low Isles	Changes to geomorphology and death of coral (*Montipora*, *Porites*) clams (*Hippopus*) Changes in community structure post event (Moorhouse 1936)
1943					5/6/44	Observations of physical damage to various reefs (Gleghorn 1947)
1977	'Otto' 'Keith'		Wet Tropics		GBR central lagoon	Phytoplankton blooms (Pickard et al. 1977)
1977–78	'Peter'	1/01/79 – 10/01/79	Wet Tropics		GBR central lagoon	Phytoplankton blooms (Revelante & Gilmartin 1982)
1979	Kerry	13/3/79–6/3/79	Burdekin	Wind gusts reached 76 knots	Adjacent and north of Burdekin catchment	Measurements of low salinity (Wolanski & Jones 1981)
1981			Burdekin			Measurements of low salinity (Wolanski & van Senden 1983)
1983	Dominic				6/4/83–11/4/83	Sedimentation at Endeavour Reef (Davies & Hughes 1983)

Table 2 cont.

1986	Winifred			175 km/hr Central pressure of 958 hPa SW–SE (1/2/86) NE-N (2/2/86)	Inshore and offshore Central	Sediment resuspended and moved across shelf (Gagan et al. 1987, 1990) Phytoplankton blooms (Furnas & Mitchell 1986)
1988	Charlie			Cape Bowling Green recorded 981hPa. Wave heights up to 3.1 m	Inshore Central	(Brodie & Furnas 1996) (Liston 1990)
1989	Aivu	Pioneer and Proserpine Rivers		959 hPa recorded 20 km from coast	Inshore and Offshore Central	3 m storm surge in Upstart Bay

Gagan et al. (1987) showed that most of the terrestrial plant detritus from the Johnstone and other Wet Tropic rivers, during floods associated with cyclone Winifred, was deposited close to the coast with none being detected further than 15 km offshore. From their study, based on carbon isotope ratios of organic matter in shelf sediment before and after the cyclone, they concluded that terrestrial run-off has not reached the mid- and outer-shelf reefs of the GBR in historical times except possibly during major Burdekin River floods. While noting the possible modifying effects of water circulation patterns on plume dispersal they did not specifically address the effects of the wind regime on the extent of influence of the flood plumes (Gagan et al. 1987). In a subsequent paper, based on shelf sediments collected immediately before and after the passage of cyclone Winifred, they demonstrated extensive sediment transport which occurred during the cyclone due to shelf sediment resuspension (Gagan et al. 1990). This study showed that tropical cyclones provide an alternative method of transporting fine-sediment and nutrients within the GBR.

Following cyclone Ivor in 1990, direct physical damage, included damage to the reef matrix, dislodgment of massive coral heads, stripping of soft corals and breaking of hard corals, occurred (van Woesik et al. 1991). There was also indirect damage from burial by sediments re-suspended during the cyclone.

Cyclone Joy (1990–91), produced significant floods in most rivers between the Barron and Fitzroy rivers (Keane 1992). Floods from the Burdekin and Fitzroy rivers lasted for a number of weeks. In the associated plume, salinity dropped to 22, 25 km east of Magnetic Island with concurrent rises in chlorophyll concentrations, a change in dominant phytoplankton species to diatoms and the presence of enhanced larval fish populations (Thorrold & McKinnon 1995; McKinnon & Thorrold 1993).

Following the major flooding in the Fitzroy River catchment from cyclone Joy (Brodie & Mitchell 1992; Prekker 1992), low-salinity plume water was observed offshore for a period of three weeks (O'Neill et al. 1992). Low-salinity water (down to 8) caused significant coral mortality (van Woesik et al. 1995; van Woesik 1991) to the fringing coral reefs around the Keppel Islands. In the Capricorn-Bunker group of reefs, more than 200 km from the mouth

of the river, salinities as low as 28 were recorded and some damage to corals was observed (Prekker 1992). Winds appeared to be a major factor influencing the movement of the plume on the shelf. During the first two weeks of the flood, fresh south-easterly winds prevailed and the plume was held close to the coast and moved to the north. In the third week of the flood the winds weakened and shifted to the north. During this period, large lobes of the plume broke away ('calving') and moved southeast toward and into the Capricorn-Bunker area (O'Neill et al. 1992).