

# EFFECTS OF TOURISM ON FRASER ISLAND'S DUNE LAKES



*By Wade Hadwen, Angela Arthington, Stuart Bunn and Thorsten Mosisch*

SUSTAINABLE  
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## Summary

The freshwater dune lakes on Fraser Island are of immense cultural, recreational and environmental value. Acknowledgement of these values contributed significantly to the successful nomination of Fraser Island as a World Heritage Area in 1992. Today, these unique aquatic systems are increasingly important recreational sites for tourists on Fraser Island. In light of the rapidly growing tourism industry in the region, there is increasing concern over the sustainability of tourist use of these oligotrophic (low nutrient) lakes. Put simply, excessive tourist use of the dune lakes on Fraser Island could deleteriously affect their ecology and in turn, their aesthetic appeal to tourists.

The production of this report marks the culmination of a study that spanned 4 years and constituted the bulk of Wade Hadwen's PhD project. In light of the perceived threat of tourist use of the dune lakes on Fraser Island, this study aimed to address the following questions:

1. Are the perched dune lakes on Fraser Island important focal areas for recreation on the island, and if so, which lakes are most popular?
2. Are any of the dune lakes on Fraser Island threatened with cultural eutrophication from tourist nutrient inputs, and is there evidence of this from comparisons with earlier studies?
3. Which nutrients, if any, limit the production of algal (phytoplankton and periphyton) communities in the littoral zone of perched dune lakes on Fraser Island?
4. Will nutrient additions, equivalent to those likely to be made by tourists, to Lake McKenzie lead to increased algal biomass?
5. What are the likely long-term consequences of ongoing nutrient additions in perched dune lakes on Fraser Island?
6. What are the implications of these research findings for ongoing monitoring of the health of Fraser Island dune lakes in light of increasing tourist numbers?

Findings from surveys conducted at Lake McKenzie suggest that the clear perched dune lakes on Fraser Island are some of the most heavily visited sites on the island. Furthermore, with in excess of 96% of respondents expressing an interest in swimming in Lake McKenzie there remains little doubt over the appeal of the system as a swimming site. Furthermore, survey respondents indicated that they favoured swimming in the clear lakes on the island beyond the brown stained lakes, streams, swimming pools and the ocean. As such, ongoing tourist use of the clear perched dune lakes on Fraser Island is likely to have significant implications for the ultimate sustainability of tourism in the region.

A novel Tourist Pressure Index (TPI) was developed to assess which lakes are most likely to be threatened by excessive tourist use. The model integrates quantitative measurements of social, logistical and biological parameters to determine a TPI score for each of the 15 most well known lakes on Fraser Island. Results indicated that Lake McKenzie, Lake Allom and Lake Birrabeen are likely to be most threatened by tourist use. Significantly, these findings further support the results of the tourist surveys showing that tourists are undeniably and disproportionately attracted to the clear perched dune lakes on Fraser Island for the bulk of their swimming and recreational activities. Coupling of TPI scores and water quality data for all 15 lakes found that in addition to being extremely popular, Lakes McKenzie and Birrabeen are two of the most oligotrophic systems on Fraser Island. In essence, these systems are likely to be amongst the most responsive to nutrient additions and given their obvious appeal with tourists, management actions should ensure that deleterious impacts from excessive tourist use are kept to a minimum.

In light of the appeal of perched dune lakes as significant swimming and recreation sites on Fraser Island, the remainder of this study aimed to investigate the likely biological and ecological consequences of nutrient additions from tourist sources on these oligotrophic systems. The first phase of the research revolved around comparisons of historical data (principally water quality and phytoplankton data collected by Arthington, Kennard and Miller (1990) with that collected in February 1999 (current study). These comparisons aimed to investigate whether or not there have been any changes in the trophic status and ecological health of the dune lakes on Fraser Island over the past decade. Not unsurprisingly, nutrient concentrations had risen markedly over the past decade in the water-table window lakes, yet they had not risen in the perched dune lakes. However, increased algal biomass (as measured by chlorophyll a concentrations) was recorded in all lakes, suggesting that nutrient additions over the past decade have led to significant increases in algal productivity. As a result, the use of ambient nutrient concentrations in Fraser Island Lake monitoring programs is potentially misleading, since nutrient additions to these oligotrophic systems may not always be reflected in changes in ambient nutrient concentrations.

These findings led to the development of more spatially and temporally appropriate monitoring in five popular perched dune lakes on Fraser Island over the course of the 1999-2000 summer. This novel monitoring approach measured nutrient and algal (periphyton and phytoplankton chlorophyll a) concentrations in disturbed (access point) and reference (inaccessible) sites within each of the lakes examined. The results of this monitoring lent further support to the suggestion that ambient nutrient concentrations may not always reflect nutrient inputs in these oligotrophic systems. On only one occasion did ambient nutrient concentrations differ between disturbed and reference sites and that occurred when sampling followed immediately after a tour group had left Basin Lake. As such, it seems as if the short residence time of nutrients in the water column of the perched dune lakes on Fraser Island seriously inhibits the usefulness of the use of ambient nutrient concentrations in monitoring programs. Similarly, it was found that phytoplankton chlorophyll a is often too variable in time and space to enable accurate examination of tourist impacts in the littoral zone. In contrast, periphyton chlorophyll a concentrations differed significantly between disturbed and reference sites over the course of the 1999-2000 summer, particularly in the clear lakes wherein light limitation of algal production is an unlikely event. In general, periphyton chlorophyll a concentrations increased over the course of the summer in disturbed sites and as such, differences between disturbed and reference site concentrations also increased through time.

Experiments using artificial substrates were subsequently designed to further examine the relationship between periphyton chlorophyll a concentrations and tourist access points to lakes. These experiments suffered from losses (removal) of substrates, but in general, artificial substrates deployed in disturbed sites accrued higher concentrations of periphyton chlorophyll a than did substrates deployed in reference sites in five heavily visited perched dune lakes on Fraser Island.

In order to determine whether nutrient additions from tourists might explain these results, algal bioassay experiments were conducted over the course of the 2000-2001 summer in each of the same five lakes. The algal bioassays delivered known quantities of nitrogen, phosphorus or nitrogen + phosphorus to phytoplankton and periphyton algal communities and the resultant biomass (as measured by chlorophyll a concentrations) was indicative of the algal response to the added nutrients. In all five lakes, added nutrients did stimulate excessive algal production and biomass accrual. However, the degree to which production was enhanced was nutrient dependent, suggesting that one or both of nitrogen and phosphorus were important limiting nutrients in these systems. Furthermore, different lakes showed signs of limitation for different nutrients, highlighting their physical and chemical differences and the need for more detailed management plans to be drawn up for these systems. These findings suggest that ongoing tourist use of the perched dune lakes on Fraser Island is likely to lead to increased nutrient inputs and subsequent increases in algal concentrations.

In summary, the findings from this research study suggest that the current level of tourist pressure on the perched dune lakes on Fraser Island is likely to have a significant long-term impact on the ecological health of these systems. Increasing periphyton biomass on natural and artificial substrates in the most accessible areas of lakes suggests that the dynamics of the most popular systems are already changing in response to heightened tourist loads. Obviously, any increases in tourist visitation levels are likely to exacerbate these changes and speed up the process of eutrophication. In short, excessive tourist use of perched dune lakes will lead to increases in algal and macrophyte biomass in the littoral zone. Ongoing nutrient additions from tourists are also likely to lead to irreversible increases in ambient nutrient concentrations. In a worst case scenario, these trends will favour the proliferation of undesirable and unpalatable forms of algae in the littoral zone, reducing the aesthetic appeal of these systems considerably.

It is likely that the sustainable use of perched dune lakes on Fraser Island by tourists will require the implementation of strict visitation regulations. These recommendations have already been made in other documents, but the data presented herein suggest that there are good scientific reasons for restrictions to be implemented promptly. Regulations may be needed at the site level or they may reflect regulation of the total number of visitors on Fraser Island as a whole, particularly during peak visitation periods such as Easter and Christmas holidays. Regardless, undesirable consequences, both ecological (eutrophication and algal blooms) and sociological (overcrowding and facilities management), are likely to be the outcome of the ongoing unrestricted use of perched dune lakes in this World Heritage Area.





## *Chapter 1*

# **Introduction**

## **Nutrient Additions in Freshwater Ecosystems**

More than any other perturbation, excessive nutrient additions from anthropogenic sources threaten the long-term health of many of the Earth's freshwater ecosystems (Guoxiang & Peimen 1999, Anon 2002a). Excessive land clearing, increasing industrialisation and the prolific use of fertilizers in agriculture have greatly accelerated the delivery of nutrients to lakes and rivers in many populated regions of the world (Henderson-Sellers & Markland 1987, Proulx, Pick, Mazumder, Hamilton & Lean 1996, Carpenter et al. 1998). The most publicised consequence of nutrient additions from human sources is eutrophication, or nutrient pollution (White 1983, Henderson-Sellers & Markland 1987, Havens, Aumen, James & Smith 1996a, Carpenter et al. 1998, Moss 1998, Anon 2002a). In these instances, excessive nutrient inputs lead to irreversible increases in ambient nutrient concentrations (Larson 1996, Guoxiang & Peimen 1999, Hakanson 2001, Havens et al. 2001, Janssen 2001).

Numerous symptoms characterise eutrophication of freshwater environments. One of the most visible symptoms is the formation of blooms of noxious algae (Turner, Robinson, Townsend, Hahn & Amaral 1995, Kelly & Whitton 1998), although eutrophication can also lead to excessive growth of aquatic macrophytes, dominance of zooplankton by small inefficient grazers and dominance of the fish biomass by benthivores (Carpenter et al. 1998). In pristine freshwater environments managed for conservation purposes, these biological responses (and subsequent increases in the trophic status or productivity of the system) are undesirable (Anon 2002a). In addition to the numerous health and social costs associated with degraded water resources (Carpenter et al. 1998, Vallentyne 1999), the biological consequences of eutrophication can also reduce the aesthetic appeal of aquatic systems (King & Mace 1974, Henderson-Sellers & Markland 1987).

Over the past three decades countless billions of dollars have been spent to control the symptoms of eutrophication and to rehabilitate affected aquatic systems (Henderson-Sellers & Markland 1987). Despite these considerable investments of time and money, eutrophication is increasingly considered to be an irreversible process in aquatic systems (Henderson-Sellers & Markland 1987, Carpenter & Cottingham 1997, Moss 1998). This irreversibility is highlighted by the fact that ambient nutrient concentrations remain high in eutrophic systems, even when symptoms such as algal blooms are controlled using a variety of mechanical and chemical measures (Henderson-Sellers & Markland 1987, Guoxiang & Peimen 1999, Hakanson 2001).

Whilst the addition of large quantities of nutrients from human sources may result in highly visible biological responses (e.g. algal blooms and fish kills), relatively minor nutrient additions can also have substantial ecological effects (Henderson-Sellers & Markland 1987, Schallenberg & Burns 1999, 2001). For example, minor nutrient additions made to a eutrophic lake may not generate a measurable response, yet the same input to an oligotrophic lake may be enough to push the system towards mesotrophy (a higher, more productive, trophic state). As a result of this relationship between system characteristics and their biological responses to nutrient additions, an understanding of the scale and magnitude of nutrient additions in particular waterbodies is essential before generalisations can be made about the likely responses and ecological outcomes of those additions (Underwood & Kennelly 1990, Underwood 1996, Lake 2000).

One example of relatively minor (small quantity) nutrient additions made at a variety of temporal and spatial scales are those from tourists visiting oligotrophic systems. Tourists can significantly change nutrient concentrations in oligotrophic systems, both through sediment (and therefore nutrient) re-suspension and direct nutrient additions (King & Mace 1974). Whilst the effect of sediment re-suspension on nutrient availability to primary producers have been the focus of numerous studies (Leuttich et al. 1990, Bailey & Hamilton 1997, James, Hawes & Weatherhead 2000) - but not from a tourist impact perspective - very few studies have investigated the consequences of direct nutrient inputs from tourists. Nevertheless, additions of soaps, detergents, sunscreens and biological wastes have the potential to considerably alter the physical and chemical conditions experienced by primary producers in aquatic systems (Craig 1977, Butler, Birtles, Pearson & Jones 1996, Eells 1997, Mosisch & Arthington 1998, 2001). Whilst some of these chemical additions may be deleterious to primary producers (Mosisch & Arthington 2001), additions of urine and other wastes are likely to promote increased primary productivity in oligotrophic systems (Butler et al. 1996, Adamsson 2000).

In addition to system characteristics, the scale at which nutrient additions are made will influence the outcomes of their addition. At the very least, the scale at which nutrients are added to oligotrophic systems should influence the design of monitoring programs (Underwood 1996). For example, recreational activities in oligotrophic waterbodies can be interpreted as a temporally variable acute (or pulse) disturbance (peak tour times and high visitation in a particular area), or a long-term chronic (or press) disturbance (consistent and/or increasing visitation levels across sites) (Underwood & Kennelly 1990, Underwood 1996, Lake 2000) (Table 1).

Direct studies of the effects of tourist activities on nutrient concentrations and algal production are rare (Leung & Marion 2000, Newsome, Moore & Dowling 2002). Instead, most studies investigating the ecological impacts of tourists on natural areas focus on the highly visible consequences of trampling on vegetation (Allison 1996, Whinam & Chilcott 1999, Monz 2002). One exception is the work of Butler et al. (1996) and their investigation of the impact of tourists on several popular swimming sites in oligotrophic streams in North Queensland. They found nutrient and algal concentrations to be significantly higher immediately downstream from tourist access points than they were upstream of those points. Their conclusion was that tourists, both through sediment re-suspension and urination, are likely to have contributed substantially to these elevated nutrient concentrations. These findings suggest that focal sites in aquatic systems may be particularly responsive and effected by nutrient additions. As such, monitoring programs investigating tourist impacts on oligotrophic aquatic systems should be designed to analyse differences between focal (impacted) and reference sites (Underwood 1996).

## **Measurement and Implications of Tourist Nutrient Additions to Lakes on Fraser Island**

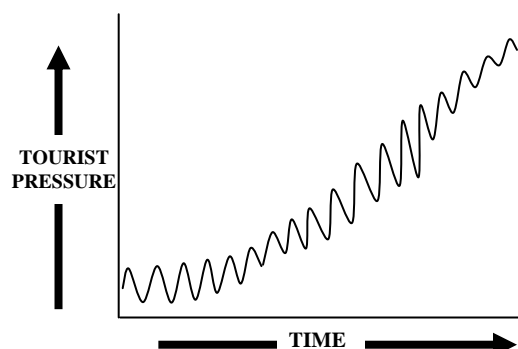
Earlier research in the oligotrophic dune lakes on Fraser Island suggests that relatively minor nutrient additions from tourist sources have the potential to have considerable ecological consequences (Arthington et al. 1990). However, as mentioned above, adequate detection of system responses to additions will rely on the implementation of monitoring programs at appropriate spatial and temporal scales (Underwood & Kennelly 1990, Underwood 1996, Lake 2000).

The need for scale-dependent monitoring of tourist impacts is particularly true for the lakes on Fraser Island, since tourist numbers on the island swell to in excess of 10 000 people during peak holiday times around Christmas (December-January) and Easter (March-April). During these peak times, the frequency of nutrient additions from tourist sources is also likely to increase. In contrast, inputs from tourists are expected to be comparatively low in winter, when the island hosts less than 1000 visitors concurrently and swimming activities in dune lakes are much reduced (personal observation). As a result of this seasonality in tourist activities, pressure from tourists on Fraser Island's dune lakes may be represented as a seasonal pulse of nutrient inputs (Figure 1). However, increasing visitation levels in winter may, in time, reduce the seasonal nature of tourism on Fraser Island, leading to summer peaks followed by much less depressed declines in winter (Figure 1). Furthermore, increasing tourist numbers from year to year represent a press (or more precisely a ramp) disturbance for the heavily visited lakes on the island (Lake 2000, Figure 1)

Further to seasonal fluctuations in visitation levels (and potentially nutrient additions), there are a variety of spatial scales at which impacts can be measured (Underwood 1996). As discussed above, nutrient additions are likely to be focussed in the areas most frequented by tourists (Leung & Marion 2000, Newsome et al. 2002). As a result, detection of impacts at the whole lake scale will require long-term monitoring of lakes, whilst detection of impacts at the within lake scale requires monitoring at much smaller spatial and temporal scales (Underwood 1996, Table 1).

Given the spatially and temporally explicit nature of nutrient additions from tourists, it is likely that responses will be detected at the within lake scale before they will be at the whole lake scale (Underwood & Kennelly 1990, Underwood 1996). As a result, differences at the whole lake scale attributable to nutrient additions may only be measurable after changes are lake-wide in their extent. Furthermore, as a consequence of the fact that they may be detected earlier than whole lake changes, undesirable within-lake changes may be reversible (Underwood 1996). Since focal site impacts may be ameliorated or controlled more easily than are lake-wide impacts, the monitoring program employed will ultimately influence the management alternatives for impacted lakes.

**Figure 1: Conceptual Diagram of Tourist Pressure on Fraser Island's Dune Lakes**



Since tourists predominantly visit Fraser Island in the warm summer months (Queensland National Parks and Wildlife Service, unpublished data), nutrient additions are likely to be made when conditions promote rapid uptake by primary producers (Dodds, Priscu & Ellis 1991, Caraco, Cole & Likens 1992). At an even smaller temporal scale, most visitors swim in the lakes on the island in the middle of the day, when temperature and light conditions are likely to enable primary producers to make immediate use of added nutrients (Rhee & Gotham 1980, Viner 1984). These temporal considerations, in conjunction with the oligotrophic nature of these systems, suggest that nutrient additions from tourist sources are likely to stimulate primary production in the lakes on Fraser Island (Outridge, Arthington & Miller 1989, Arthington et al. 1990).

**Table 1: Spatial and temporal scales of nutrient additions and their detection in lakes visited by tourists**

<b>SPATIAL DISTRIBUTION OF NUTRIENT ADDITIONS</b>		
<b>FOCAL ADDITIONS</b>		
<b>LAKE-WIDE ADDITIONS</b>		
<b>TEMPORAL DISTRIBUTION OF NUTRIENT ADDITIONS</b>	<b>ACUTE ADDITIONS</b>	<p>ISSUE: How are accessible sites affected by elevated nutrient additions during peak tour times?</p> <p>DETECTION: Before After Control Impact approach – sampling in disturbed and reference sites before, during and after peak tour times.</p>
	<b>CHRONIC ADDITIONS</b>	<p>ISSUE: How do ongoing additions affect accessible sites within lakes?</p> <p>DETECTION: Long-term sampling at disturbed sites.</p>
		<p>ISSUE: How do nutrient additions during peak tour times affect the entire lake?</p> <p>DETECTION: Spatially replicated sampling within lakes before, during and after peak tour times.</p>
		<p>ISSUE: What are the long-term consequences of rising visitation levels (and nutrient inputs) for these lakes?</p> <p>DETECTION: Long-term monitoring of effects of nutrient additions in a range of variously visited lakes.</p>

Increased primary production may, in itself, not pose a problem to the long-term conservation of lakes on Fraser Island. However, increased availability of nutrients may lead to rapid changes in the composition of algal communities (Healey 1979, Lehman & Sandgren 1985, Suttle, Stockner & Harrison 1987). Phosphorus-rich nutrient sources may particularly influence community composition through the promotion of conditions favouring an increase in the relative abundance of N-fixing cyanobacteria (McQueen & Lean 1987, Levine & Schindler 1999).

In addition to potential producer compositional changes, repeated inputs might stimulate algal production beyond the regulatory control of primary consumers (Hunter 1980, Henderson-Sellers & Markland 1987, Carpenter et al. 1996, Saunders, Shaw & Bukaveckas 2000). If consumers cannot regulate algal production, continued nutrient additions may lead to increases in the frequency of algal blooms (Schmitz 1997) as well as the development of undesirable quantities of algal biomass (Hunter 1980).

### **Aims and Outline of Study**

This study investigates the potential consequences of tourist use of the oligotrophic perched dune lakes within the Fraser Island World Heritage Area, Australia. In particular, the research aimed to answer the following questions:

1. Are the perched dune lakes on Fraser Island important focal areas for recreation on the island, and if so, which lakes are most popular?
2. Are any of the dune lakes on Fraser Island threatened with cultural eutrophication from tourist nutrient inputs, and is there evidence of this from comparisons with earlier studies?
3. Which nutrients, if any, limit the production of phytoplankton and periphyton communities in the littoral zone of perched dune lakes on Fraser Island?
4. Will nutrient additions, equivalent to those likely to be made by tourists, to Lake McKenzie lead to increased algal biomass?
5. What are the likely long-term consequences of ongoing nutrient additions in perched dune lakes on Fraser Island?
6. Based on the findings of this work, what are the implications for ongoing monitoring of tourist impacts on oligotrophic dune lakes?

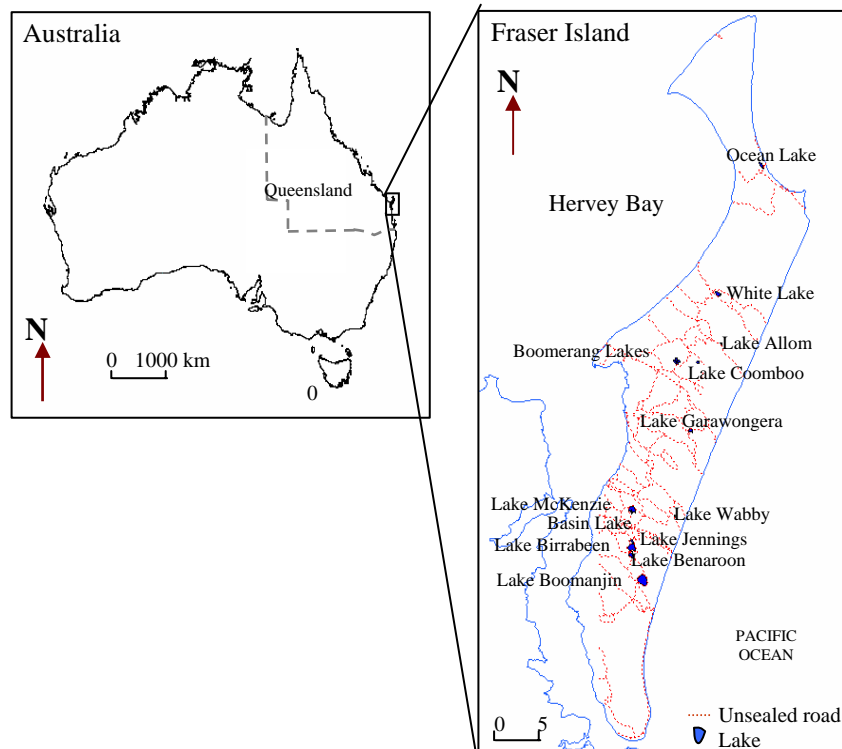
## Chapter 2

# Study Area And Characteristics Of Dune Lakes

## Location of Fraser Island

Occupying an area of 166 283 hectares between 24° 35' - 26° 20'S and 152° 45' - 153° 30'E off the Queensland coast (Figure 2), Fraser Island is the largest sand island in the world (Anon. 1999, UNESCO 2001). The island consists largely of a series of sand dunes of Gondwanan origin (Barson 1997, Anon. 1999, UNESCO 2001).

**Figure 2: Location of Fraser Island, south-eastern Queensland, featuring well-known lakes and unsealed roads**



## Climate and Vegetation

Fraser Island's subtropical climate is strongly influenced by the Pacific Ocean to the east (Figure 2), with mean annual temperatures ranging from 14.1°C to 28.8°C (Anon 1999). Rainfall on the island is high, with in excess of 1800 mm falling on the highest dunes each year (Anon 1999). Interestingly, Fraser Island is believed to be one of the few regions in Australia where annual precipitation exceeds annual evaporation (UNESCO 2001).

Despite being comprised of infertile sands, Fraser Island is characterised by having considerable floristic diversity. Seven main vegetation types occur on the island: 1) closed forest including rain forest and tall eucalypt forest dominated by satinay (*Syncarpia hillii*) and brushwood (*Lephostemon confertus*); 2) blackbutt (*Eucalyptus pilularis*) forest; scribbly gum (*Eucalyptus racemosa*) and wallum banksia (*Banksia robur*, *Banksia serrata*, *Banksia integrifolia*) communities; 3) communities of wet sites often dominated by tea trees (*Melaleuca* spp.); 4) coastal communities; 5) Callitris forest and woodlands; and 6) mangrove and saltmarsh (Anon, 1990). The first of these vegetation types, where rainforest grows on elevated sand dunes, is believed to be a globally unique ecosystem (UNESCO 2001). The plant communities on Fraser Island are strongly associated with dune sand salinity, age and nutrient status, as well as depth to the water-table and their exposure to and the frequency and intensity of fires (Sinclair & Morrison 1990).

## History of Human Inhabitation

Despite no archaeological evidence for occupation prior to 2000 years ago, aboriginal people are thought to have occupied the Fraser Island region for about 40,000 years (UNESCO 2001). Four main groups of Aborigines are said to have inhabited Fraser Island when Europeans first arrived in the region in the 1800's (UNESCO 2001).

Despite being driven from the island by Europeans shortly thereafter, visible signs of Aboriginal occupation (such as shell middens) still remain (Sinclair & Morrison 1990).

The settlement of Europeans on Fraser Island led to the development of a number of environmentally destructive extraction industries (UNESCO 2001). The first was the establishment of logging operations on the island in the late 1800's (UNESCO 2001). Whilst many trees were destroyed by logging activities, particular rainforest tree species were preferentially harvested. For example, satinay trees (*Syncarpia hillii*) were highly sought after due to their resistance to marine borers (Anon 1999). In the middle of the twentieth century, an extractive sand mining industry was also established on Fraser Island (UNESCO 2001). Sand mining leases led to the destruction of 150 hectares of vegetation on the island (UNESCO 2001).

In recognition of the island's natural heritage value and in response to considerable pressure applied by local community and interest groups in the 1960's and 1970's, the Australian Federal Government prohibited sand mining on Fraser Island in 1975 (UNESCO 2001). Ongoing lobbying from interest groups (including FIDO, the Fraser Island Defender's Organisation) also contributed to the cessation of logging operations on the island in 1992, the same year in which Fraser Island was declared a World Heritage Area (UNESCO 2001). According to the World Heritage Convention, the region satisfied two of the four natural heritage criteria stating "that natural properties should: (ii) be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals, and, (iii) contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance" (UNESCO 2001).

The World Heritage listing of Fraser Island coincided with (and presumably contributed to) a boom in the tourism industry in the region (Sinclair 2000, UNESCO 2001, Anon 2002b). Ironically, tourism now poses some significant environmental threats to the long-term preservation of the island's ecosystems (Sinclair 2000). With in excess of 300,000 visitors annually, tourism now poses a host of environmental issues, including problems of erosion, litter and waste disposal, amenities, human-wildlife interactions and contamination of the island's freshwater resources (Sinclair 2000). Whilst some of these issues have been at the forefront of management plans for the region (Anon 1991), others are yet to be adequately addressed (Sinclair 2000). Whilst there is growing concern that the activities of tourists may lead to substantial increases in nutrient concentrations in the dune lakes on Fraser Island, the current quarterly and unreplicated monitoring program for the region is spatially and temporally inadequate to detect within-lake changes attributable to tourist nutrient additions.

## **Dune Lake Ecosystems**

Dune lakes differ from other lentic systems by virtue of their peculiar modes of formation and their close proximity to the ocean (Timms 1977). Together, these geomorphological traits determine the physical and chemical features of dune lakes. Although there is a general paucity of literature referring to dune lake systems outside of Australia, studies of dune waterbodies have been conducted in New Zealand (Cunningham, Moar, Torrie & Parr 1953, Green 1976, Cassie & Freeman 1980), Great Britain (Biswas 1975), The Netherlands (Leentvaar 1963, Londo 1967, Leentvaar 1997) and North America (Kling 1986). Many of these overseas systems have physical and chemical characteristics similar to those on Fraser Island, however, their modes of origin and associated hydrologies are quite different (Timms 1986a, Leentvaar 1997).

On the basis of his studies of dune lake systems along the eastern coast of Australia, Timms (1982) categorised six main types of dune lakes in relation to their geomorphological traits and origins. These include perched lakes on leached dunes (type 1), lowland lakes on leached dunes (type 2), water-table window lakes (type 3), dune-contact lakes (type 4), freshwater lakes with marine contact (type 5) and ponds in frontal dunes (type 6) (Table 2).

Water-table window lakes, marine contact lakes and perched lakes are the most common forms of dune lakes encountered along the coast of eastern Australia (Bayly 1964, Timms 1982, James 1984). Whilst water-table window and marine contact lakes typify those along the south eastern regions of the Australian coastline, perched dune lakes are particularly abundant in the coastal lowlands of Southern Queensland, particularly on North Stradbroke, Moreton and Fraser Islands (Bayly 1964, Timms 1982).

## **Perched Dune Lakes in South-East Queensland**

As their name suggests, perched dune lakes sit in depressions that lie above the regional aquifer (James 1984). They do not typically have inflow or outflow creeks (Figure 3, Bayly 1964) and as such, perched systems only form when sand becomes cemented together with organic matter to form an impermeable B-horizon soil known as "coffee rock" (Bayly, Ebsworth & Wan 1975, James 1984). As a consequence of this unique mode of origin, perched dune lakes are generally regarded as morphologically simple and hydrologically closed basins of rainwater (Bayly et al. 1975, Bowling 1988, Arthington et al. 1990).

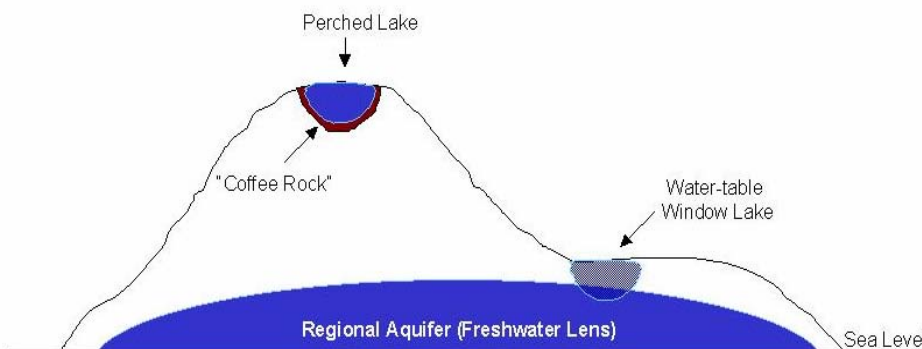
Owing to the fact that rainfall on Fraser Island exceeds water loss via evaporation, very few of the island's perched dune lakes dry out (UNESCO 2001). In fact, Longmore (1986, 1997) found that some perched dune lake

sediments contain a continuous history (in excess of 300,000 years) of the island's hydrology and vegetation changes through Quarternary glacial and interglacial periods (UNESCO 2001).

**Table 2: Dune lake types according to the classification of Timms (1982)**

LAKE TRAITS	Type 1. Perched lakes on leached dunes	Type 2. Lowland lakes on leached dunes	Type 3. Water-table window lakes	Type 4. Dune-contact lakes	Type 5. Fresh-water lakes with marine contact	Type 6. Ponds in frontal dunes
<b>Water Clarity</b>	Opaque, from humic flow-off	Opaque, from humic flow-off	Clear groundwater	If deep, clear groundwater, if shallow, opaque	Depends on hydrology. Like dune-contact lakes	Clear groundwater
<b>Total Dissolved Solids (TDS)</b>	High TDS due to leached organic acids	High TDS due to leached organic acids	Low TDS	Low TDS	High TDS from sea water	Low TDS
<b>Water Chemistry</b>	Dominated by Na <sup>+</sup> and Cl <sup>-</sup>	Dominated by Na <sup>+</sup> and Cl <sup>-</sup>	Dominated by Na <sup>+</sup> and Cl <sup>-</sup>	Dominated by Na <sup>+</sup> and Cl <sup>-</sup>	Variable	Dominated by HCO <sub>3</sub> <sup>-</sup> and Ca <sup>2+</sup>
<b>pH</b>	4.5 – 4.7 (acidic)	5.5 (acidic)	6.0 (acidic)	5.5 (acidic)	Variable	8.0 (alkaline)
<b>Littoral Vegetation</b>	<i>Lepironia articulata</i> dominates	<i>Typha</i> sp., <i>Phragmites australis</i> , <i>Cladium procerum</i> , <i>Leptocarpus tenax</i> and <i>Scirpus litoralis</i> .	Same as Lowland lakes on leached dunes (Type 2).	<i>Lepironia articulata</i> dominates	Same as Lowland lakes on leached dunes (Type 2).	No littoral vegetation, generally terrestrial vegetation
<b>Invertebrates</b>	<i>Calamoecia tasmanica</i> dominates the zooplankton	<i>Calamoecia tasmanica</i> dominates zooplankton. Sporadic appearance of ostracods and molluscs	<i>Calamoecia tasmanica</i> joined or replaced by cyclopoid zooplankton	Regular presence of ostracods, molluscs, leeches and cladocerans	Ostracods and molluscs with marine affinities dominate.	<i>Calamoecia tasmanica</i> , shrimps, Ostracods and molluscs common.

**Figure 3: Diagrammatic representation of perched and water-table window dune lakes**



**Physical and Chemical Features of Perched Dune Lakes**

Since the basins of perched dune lakes are filled only by local rainfall and associated runoff, they are ironically similar to rainwater (Bayly 1964, Bayly & Williams 1972). Given that most of the rainfall on Fraser Island comes from the east, off the Pacific Ocean (UNESCO 2001), Na<sup>+</sup> and Cl<sup>-</sup> ions are dominant. Furthermore, since the sands of Fraser Island are siliceous rather than calcareous, concentrations of Ca<sup>2+</sup> and CO<sub>3</sub><sup>-</sup> ions are characteristically low (Timms 1986a).

Perched dune lakes are acidic due to the large quantities of organic acids leached from humic material washed from their catchments (Bayly 1964, Timms 1982). Arthington et al. (1990) reported pH values from 3.3 and 5.5 for perched dune lakes on Fraser Island and Bayly et al. (1975) found a relationship between Secchi disc depth and pH in perched dune lakes, presumably because high concentrations of humic acids contribute to light attenuation (Bayly 1964).

As a consequence of their origins and hydrologies, nutrient concentrations in perched dune lakes are characteristically very low, with total phosphorus concentrations in some lakes not exceeding the minimal detectable limits of 2 µg/L (Arthington et al. 1990, Hockings 1999). Total nitrogen concentrations are considerably more variable (owing to the variable concentrations of dissolved humic matter in these systems - Arthington et al. 1990, Hockings 1999). Although there have been no experimental analyses of productivity conducted in the perched dune lakes of Fraser Island, standing phytoplankton biomass (measured as chlorophyll a concentration) is generally lower than that reported for other lentic systems (Bayly 1964, Arthington, Burton, Williams & Outridge 1986, Timms 1986a, Outridge et al. 1989, Arthington et al. 1990).

### **Biota of Perched Dune Lakes on Fraser Island**

In addition to their unique mode of origin (which, according to Timms (1986a), makes colonisation by truly aquatic organisms difficult), the acidic Na<sup>+</sup> and Cl<sup>-</sup> dominated water of perched dune lakes is said to play a strong role in determining the species composition of ecological communities (Bayly 1964, 1966). Only acid tolerant species thrive in these systems, as testified by significant populations of the rare fish honey blue-eye *Pseudomugil mellis* and the Oxleyan pygmy perch *Nannoperca oxleyana* (Arthington 1984, Arthington et al. 1986, UNESCO 2001) and the geographically rare and restricted “acid frogs” such as the Wallum froglet *Crinia tinnula*, the Cooloola sedgefrog *Litoria cooloolensis*, the Wallum rocketfrog *L. freycineti* and the Wallum sedgefrog *L. olongburensis* (UNESCO 2001). Despite the presence of these acid lake specialists, Timms and Watts (1981) found that some of the aquatic beetle species found in these systems are comparatively widespread taxa, presumably due to their wide tolerances to acidity and generalist diet requirements.

Courtesy of their hydrologic isolation from one another and from the regional aquifer, the faunal composition of perched dune lakes is both spatially variable and species poor (Timms 1986a, 1986b). Recent studies have suggested that the distribution of aquatic species may be facilitated by the activities of the local avifauna, since eggs can often adhere to the feet and feathers of waterbirds (Leentvaar 1997, Figuerola & Green 2002). However, this hypothesis seems unlikely for perched dune lakes given that their acidic unproductive waters tend not to attract large numbers of waterbirds (Bayly 1964, Bayly et al. 1975).

### ***Phytoplankton***

Phytoplankton communities in perched dune lakes are dominated by acid-tolerant groups such as the desmids, diatoms and dinoflagellates (Bayly et al. 1975, Bayly 1980, Timms 1986a, Bowling 1988, Hawkins, Taplin, Duivenvoorden & Scott 1988, Outridge et al. 1989). Detailed temporal investigations of phytoplankton communities in seven Fraser Island dune lakes were conducted in the late 1980's by Arthington et al. (1990). Desmids and other green algae were found to comprise 50-75% of the phytoplankton diversity. Although general patterns in species composition were difficult to resolve, Arthington et al. (1990) suggested that the majority of the perched dune lakes were dominated by blue-green algae (Cyanophyceae) and dinoflagellates (Dinophyceae), whilst the water-table window lakes were dominated by green algae (Chlorophyceae) and diatoms (Bacillariophyceae). These findings suggested that the more nutrient enriched water-table lakes had fewer blue-green algal (Cyanophyceae) components than did the nutrient poor, perched dune lakes. Despite this overall trend, Arthington et al. (1990) suggested that the data “do not suggest any simplistic approaches (such as dominance of blue-green algae) to the classification of the lakes or the assessment of their trophic status”.

Whilst algal blooms have never been recorded in perched dune lakes on Fraser Island, the nearby Lake Freshwater in the Cooloola National Park experienced a bloom of blue-green algae in 1989 (Outridge et al. 1989). Outridge et al. (1989) postulated that increased visitation by tourists was at least partially responsible for increased nutrient levels and the subsequent bloom of blue-green algae at that time.

### ***Periphyton***

The biomass and species composition of periphyton communities in the littoral zones of perched dune lakes has received almost no formal attention. Bensink and Burton (1975) mentioned that clumps of *Syctonema* sp. were common on reeds within the littoral of Blue Lake on North Stradbroke Island, yet no other investigations have focussed any attention on benthic or littoral algae.

### ***Aquatic Macrophytes***

Aquatic macrophytes are generally rare in the perched dune lakes on Fraser Island (Bayly et al. 1975, Arthington et al. 1986). However, littoral zone stands of the sedge *Lepironia articulata* are common, and this species is strongly associated with many of the dune lakes of Australia's east coast (Timms 1969, Bensink & Burton 1975, Arthington et al. 1986, Timms 1986a, 1986c; Hawkins et al. 1988). Owing to the oligotrophic nature of perched dune lakes, aquatic and semi-aquatic carnivorous plants are locally abundant (Bayly 1966). Sundews (*Drosera* spp.) and bladderworts (*Utricularia* sp.) commonly occupy the littoral fringe in and around perched dune lakes, supplementing their nutrient requirements by consuming small aquatic and terrestrial invertebrates (Bayly 1966).

### ***Zooplankton and Epilimnetic Communities***

The epilimnetic communities of Fraser Island perched dune lakes are extremely species poor (Bayly 1964, Bayly et al. 1975, Timms 1986a). Communities are always dominated numerically by the calanoid copepod, *Calamoecia tasmanica*, although other zooplankton species are occasionally found (Bayly 1964, Bayly et al. 1975, Bensink & Burton 1975, Timms 1982, Arthington et al. 1986, Timms 1986a). Additional yet numerically rare limnetic organisms include chironomids (Chironomidae) (Bensink & Burton 1975, Arthington et al. 1986) and larval *Chaoborus* sp. (Chaoboridae) (Bayly 1966, Timms 1973, Bensink & Burton 1975, Arthington et al. 1986, Timms 1997). The low abundance and infrequent occurrence of *Chaoborus* sp. has been suggested to be a consequence of predation by fish, as evidenced by the strong negative relationship between the presence of fish and *Chaoborus* sp. in Fraser Island dune lakes (Bayly et al. 1975, Bensink & Burton 1975, Arthington et al. 1986).

### ***Littoral Macroinvertebrates***

The acidity and relatively low concentrations of  $\text{Ca}^{2+}$  and  $\text{HCO}_3^-$  in perched dune lakes are presumably responsible for the complete absence of molluscs, planarians, rotifers, amphipods, isopods and ostracods in the littoral zone (Bayly 1964, Timms 1986b). Nevertheless, the littoral macroinvertebrate fauna of perched dune lakes is quite diverse (Bayly et al. 1975, Arthington et al. 1986), particularly among the numerically abundant aquatic insect groups of Ephemeroptera, Odonata and Trichoptera (Bayly 1964, 1966; Timms 1969, Bayly et al. 1975, Arthington et al. 1986, Norris, Moore, Maher & Wensing 1993). There is also a reasonably high degree of endemism within some groups (Timms 1986a). For example, several species of Odonates are restricted to acidic dune lake systems (Timms & Watts 1981, Arthington & Watson 1982, Timms 1986a, 1986b). The abundance of aquatic coleopterans and hemipterans is spatially variable (Timms 1986a) and is presumably due to the patchy distribution of predatory fish within these systems (Bayly et al. 1975, Arthington et al. 1986). Additional littoral organisms include the crustaceans *Paratya* sp. (Atyidae) (Timms 1973, 1997) *Macrobrachium* and *Caridina indisincta* (Atyidae) (Bensink & Burton 1975, Arthington et al. 1986) as well as water mites such as *Limnesia* sp. (Timms 1973, Bayly et al. 1975, Bensink & Burton 1975, Arthington et al. 1986).

The profundal benthic fauna of dune lakes is depauperate (Timms 1986a, 1986b; Norris et al. 1993, Timms 1997). *Chaoborus* sp. and chironomid larvae are said to dominate sediment samples in Australian dune lakes (Bayly 1966, Arthington et al. 1986, Timms 1986), although numerous studies have been unable to detect any macroscopic benthic organisms (Norris et al. 1993, Timms 1997).

### ***Vertebrates***

The patchiness in species distributions in perched dune lakes is highlighted by the fact that some lakes have no resident fish species, whilst others have several (Bensink & Burton 1975, Arthington et al. 1986, Norris et al. 1993, Timms 1997). As mentioned above, fishless dune lakes can also be characterised by their abundance of corixids, notonectids and *Chaoborus* sp. (Bayly et al. 1975, Bensink & Burton 1975, Bayly 1980, Timms 1986a, 1986c).

As a consequence of the barriers to colonisation that perched dune lakes pose to aquatic organisms, fish species richness in Fraser Island perched dune lakes is generally low. However, most systems contain the soft-spined rainbowfish, *Rhadinocentrus ornatus*, and/or the fire-tailed gudgeon, *Hypseleotris galii* (Bayly et al. 1975, Bensink & Burton 1975, Timms 1982, 1986a). Given the low productivity of perched dune lakes (Bayly et al. 1975, Arthington et al. 1986), the long-term maintenance of fish populations in perched dune lakes is dependent upon the ability of fish species to supplement their diets with a wide range of allochthonous food sources, including pollen and terrestrial insects (Arthington et al. 1986).

There are several freshwater turtle species found on Fraser Island (Georges 1982, Arthington et al. 1986). *Chelodina longicollis* is the most common dune lake inhabitant (Bensink & Burton 1975, Timms 1997), although *Emydura krefftii* and *C. expansa* have also been collected from several lakes (Arthington et al. 1986). As for the fish, freshwater turtle populations are heavily subsidised by allochthonous food sources (Georges 1982). Georges, Norris and Wensing (1986) found that turtles living in similarly unproductive dune lakes in Jervis Bay (NSW) frequently migrated from one lake to the next in search of adequate food resources. As such, *Chelodina longicollis* is likely to be able to persist in perched dune lakes only by virtue of its mobility and flexible diet (Georges et al. 1986, Kennett & Georges 1990).



### *Chapter 3*

## **How Important are Dune Lakes as Swimming and Recreation Sites on Fraser Island?**

### **Introduction**

The growing desire for tourists to experience wilderness and adventure holidays is increasingly threatening the long-term preservation of natural areas (Gosselin 1998). In response to these pressures, several well-known National Parks in the United States have recently revised their management strategies to safeguard them from the tens of thousands of visitors they receive each year (Glick & Murr 1997). Whilst these interim measures are implemented to ameliorate the short-term effects of tourists on the natural environment (Sun 1985), the development and implementation of scientifically based management strategies is likely to be the best way of ensuring long-term preservation and sustainable tourist use of wilderness areas (Sun & Walsh 1998).

Unfortunately, however, the scientific information required to underpin the implementation of sustainable management plans is rarely available and as such, there tends to be a gap between current management strategies and long-term conservation goals. For instance, it was previously thought that increasing visitor numbers to natural areas would enhance management, since a profitable tourist industry can financially out-compete other commercial land uses (Anon. 1995, Wang & Miko 1997). Furthermore, tourists can directly generate funds for management bodies whilst concurrently increasing interest in the preservation of natural resources in the broader community (Norris 1992, Wall 1997, Gossling 1999, Tyler & Dangerfield 1999). Whilst these ideas seem fiscally sound, experience has taught us that increasing tourist numbers do not always equate to enhanced management and preservation of natural areas (Norris 1992, Glick & Murr 1997). As a result, the current goal for resource managers is to establish a sustainable balance between the protection of natural resources (meeting the philosophical aims of National Parks) and the promotion of tourism activities in natural areas (meeting commercial and funding needs) (Buckley & Pannell 1990, Anon. 1995, Butler et al. 1996, Buckley 1998).

To complicate matters, the international status of natural areas can add another level of complexity to finding the balance between preservation and funding. For example, the World Heritage listing of Fraser Island (Australia) in 1988 has contributed to increasing international awareness and subsequent expansion of tourism ventures in the region (Sinclair 2000). In the year 2000 alone, in excess of 300,000 tourists visited the island and in peak tour times around Christmas and Easter up to, 10,000 people can be on the island concurrently (Queensland National Parks and Wildlife Service, unpublished data). Somewhat ironically, this natural World Heritage Area is now becoming increasingly threatened by its international popularity as a tourist destination.

The physical presence of large numbers of tourists is already taking its toll on the island's fragile terrestrial environments, particularly via the process of erosion along foredune areas (Sinclair 2000). In addition, the risk of tourist impacts on the ecological health of the dune lakes on Fraser Island has also received attention (Steele 1999). These freshwater lakes are undeniably the focus of much of the tourism in the region (Sinclair 2000, UNESCO 2001) as they formed an important part of the island's World Heritage nomination, by virtue of their number, elevation, beauty, unique wildlife and unusual morphology and hydrology (Bayly 1966, Bayly *et al* 1975, Arthington et al. 1986, Sinclair 2000, UNESCO 2001). According to Outridge et al. (1989) and Arthington et al. (1990), their appeal to tourists, in conjunction with their unique ecological characteristics, makes these systems particularly susceptible to impacts. Undesirable ecological changes in these lakes are most likely to be driven by nutrient additions from tourists (especially from bathing and urine), as these systems are naturally oligotrophic or nutrient poor (phosphorus concentrations rarely exceeding 5 µg/L – Bayly 1966, Bayly et al. 1975, Arthington et al. 1986, Arthington et al. 1990). In addition to their anticipated responsiveness to nutrient inputs, perched lakes are hydrologically closed systems (i.e. there are usually no outflow streams and they are not connected to the regional aquifer), so additions will accumulate over time (Bayly 1964, Bayly et al. 1975, James 1984, Arthington et al. 1990). In a worst case scenario, the addition and subsequent accumulation of nutrients in these lakes could lead to increases in algal biomass as well as deleterious changes in food web dynamics, resulting in local extinctions of rare fauna and flora and/or drastic declines in water quality (Outridge et al. 1989, Arthington et al. 1990, Proulx et al. 1996). In response to the threat of nutrient additions from tourists, the island's management body (Queensland National Parks and Wildlife Service) has recently banned the use of sunscreens and other chemicals (soaps and detergents) in these unique aquatic systems (Steele 1999).

Whilst several studies have endeavoured to monitor long-term changes in dune lakes brought about by the activities of tourists, none has sought to establish the importance of perched dune lakes as swimming and recreation sites. Despite being ignored in previous studies, this information is vital to the development of long-term management strategies for Fraser Island, particularly through the identification of areas of concern for monitoring and management. In addition, it is important for resource managers to understand the type of tourist that Fraser Island attracts, particularly with regard to their environmental awareness and motivations whilst on the island.

In conjunction with the limnological investigations of tourist impacts on the perched dune lakes on Fraser Island this component of the research involved the implementation a tourist survey conducted at one of the most popular perched dune lakes on the island. The survey aimed to gain an understanding of which lakes were popular with visitors to Fraser Island, with particular emphasis on recording the types of activities people like to partake in whilst at lakes. In addition, the length of time spent swimming in Lake McKenzie was of interest, as were the perceptions of tourists with regards to their impressions on various measures of water quality.

**Method**

***Study Area***

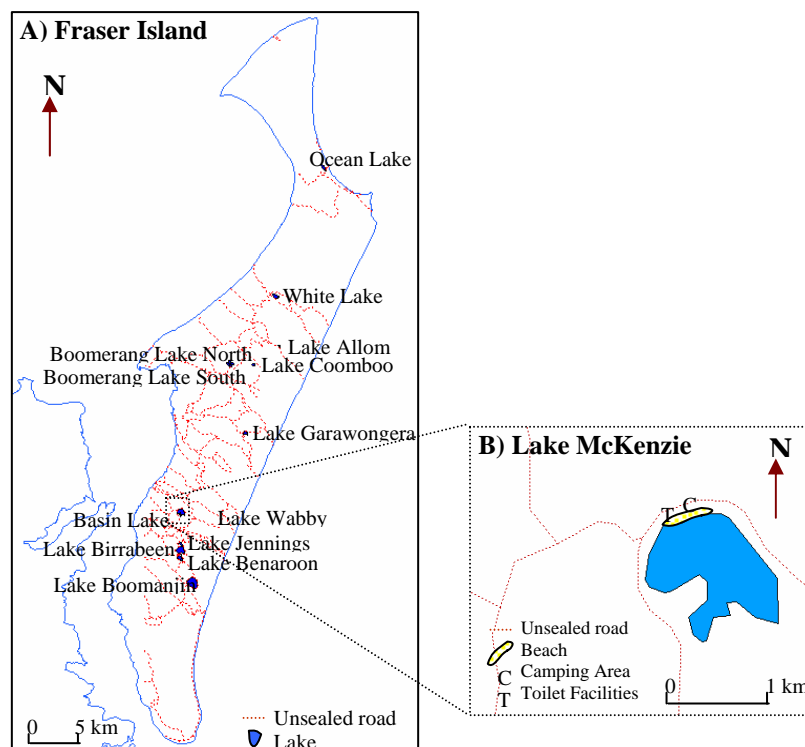
Lake McKenzie is arguably the most marketed and renowned site on Fraser Island (Sinclair 2000). The crystal clear waters have featured in numerous advertisements and the lake is a common feature on Fraser Island souvenirs. This ongoing publicity ensures that Lake McKenzie is one of the most visited sites on the island, especially in the peak tour times throughout summer (Figure 4).

**Figure 4: Tourists swimming and sunbathing at Lake McKenzie on Australia Day, 26 January 2001**



The central location of Lake McKenzie and its proximity to other tourist sites on Fraser Island, undoubtedly contributes to this popularity, as it is accessible to both day-trippers and tourists spending more lengthy stays on the island (Figure 5).

**Figure 5: a) Lakes and roads on Fraser Island; b) Detailed map of Lake McKenzie, with location of main beach as well as camping and toilet facilities**



## **Study Methods**

Based on unpublished surveys used for similar purposes (Butler et al. 1996, Mosisch & Arthington 1996), a tourist survey was developed to collect information and demographic details from tourists at Lake McKenzie (Appendix A). Survey respondents were asked questions relating to the duration and nature of their visit to Fraser Island, the size of their travelling group and the activities undertaken whilst at Lake McKenzie. In addition, several questions gathered information on the quality of their experiences at the lake, both with regard to the facilities provided as well as the water quality of the lake and its significance to the quality of their experience.

Surveys were conducted on Tuesday 13 December 1999, Friday 17 March 2000, Wednesday 6 December 2000, Thursday 7 December 2000 and Friday 26 January 2001 and on each occasion respondents were randomly selected along the main stretch of shoreline at Lake McKenzie (approximately 200m). Respondents were observed to fill in their surveys independently or in small groups.

## **Results**

A total of 154 completed surveys were collected across the five sample days, and almost 80% of the respondents were first time visitors to Fraser Island. The duration of visits was variable, although most (64%) were on the island for a period of 3-6 days and only 8% planned to stay on the island longer than 7 days (Table 3).

Among respondents staying on the island overnight, camping was by far the most nominated (68%) form of accommodation (Table 3). Undeveloped campsites along the eastern shoreline of the island were more commonly utilised (38%) than were designated campsites (30%). Resorts and Hotels on the island accommodated 26% of the respondents, indicating that despite their great capacity for housing tourists, they accounted for just over one quarter of the tourist load censused at Lake McKenzie across the five survey dates. Private houses on freehold land accounted for just 6% of those surveyed.

Whilst many respondents were travelling in very large organised tour groups (often between 20 and 40 people travelling in large privately run 4WD buses), those travelling independently were also in reasonably large groups, averaging in excess of 5 adults. Interestingly, children were under-represented (< 1 per group) despite the fact that 54% of respondents indicated that they were travelling with family and friends.

More than 75% of survey respondents indicated that they had planned to visit Lake McKenzie before coming to the island. Since more than 78% of the respondents had never before been to Lake McKenzie, this statistic highlights the widespread popularity and publicity of this lake.

Only 22% of those surveyed had been to Lake McKenzie more than once on their current visit. This result indicates that despite its popularity, Lake McKenzie does not receive large numbers of repeat visitors, unless they return on subsequent visits to the island (approximately 20% of respondents had been to Fraser Island before).

More than 95% of those surveyed expressed an interest in swimming in Lake McKenzie (Table 3). In addition, most respondents indicated a preference towards recreational activities based on relaxation, with more than 55% nominating relaxing and reading, more than 50% nominating sunbaking and more than 42% nominating general sightseeing and photography as activities planned for their time at Lake McKenzie. The more active pursuits of hiking, playing sport and kayaking were less frequently nominated (approximately 19%, 15% and 1%, respectively).

Whilst more than 88% of the respondents had swum in Lake McKenzie before answering the survey, most indicated that they had spent very little time in the water (Table 3). More than 30% of all swimmers spent less than 10 minutes in the water and about three-quarters of all swimmers spent less than half an hour in the lake. Despite this trend towards short swims, a small number of respondents (about 10%) indicated that they had spent more than 1 hour swimming in the lake.

For those that did swim in Lake McKenzie, a series of questions relating to water quality parameters were answered along a continuum from 1 to 5, with 1 indicating that the variable was not at all important in influencing the respondent's decision to swim in the lake and 5 indicating that the factor was very influential (see Question 11, Appendix A). For the majority of respondents, the clearness and purity of the water (average score 4.4) was the most important factor influencing their decision to swim. Similarly, it was important to the majority of respondents that they were swimming in a natural setting (score of 4.1), free of constructed boardwalks and other built features.

Water temperature and accessibility were generally only slightly important (scores of 3.3 and 3.2 respectively) whilst the facilities provided and the number of people present at the site made relatively little difference (scores of 2.3 and 2.8, respectively) to people's decisions on whether or not to swim. In corroboration of the importance attributed to water clarity, all respondents suggested that the quality of the water at Lake McKenzie was fair or better, with most indicating that it was excellent (68%) and that it had added greatly (77%) to the satisfaction of their swim.

Most respondents felt that the number of people present at Lake McKenzie at the time they were surveyed was about right (63%), although most others felt that there were too many people on the lake shoreline. Whilst

four respondents (approximately 3%) felt that the facilities provided at Lake McKenzie were poor, 27% felt that the facilities provided were fair, 49% thought they were good and 21% thought that they were excellent. Whilst these statistics seem to indicate that tourist satisfaction with regards to facilities provided at Lake McKenzie is high, further questioning of respondents indicated that the apparent lack of facilities was at least partially responsible for generating this relatively high level of satisfaction. In other words, the absence of facilities meant that the site appeared to be more natural and in many cases, this was regarded favourably by survey respondents.

Over two thirds of respondents had not visited any other lakes on Fraser Island at the time they were surveyed (Table 3). The central location of Lake McKenzie suggests that this result may be a little misleading however, as many of the survey respondents had just arrived on the island and had not yet had the chance to visit any other lakes. Nevertheless, several of the survey respondents did not have plans to visit any other lakes on the island (personal communication). For some respondents who had not planned on visiting other lakes during their stay on the island, the positive experience at Lake McKenzie encouraged them to consider further visits to lakes.

Of the 49 individuals surveyed that had visited other lakes, the most visited lake was Lake Wabby (47 visits). Other lakes visited were Basin Lake (22 visits), Lake Birrabeen (12 visits) Lake Boomanjin (11 visits), Lake Jennings (6 visits), Ocean Lake (5 visits), Lake Benaroon (4 visits) and Lake Garawongera and Lake Allom with one visit each (see Figure 5). Significantly, almost 60% of those that had visited other lakes had swum in at least one of them, indicating that other lakes on the island are used by tourists for swimming purposes.

**Table 3: Summary of results from tourist surveys conducted at Lake McKenzie between December 1999 and January 2001**

<b>SURVEY RESPONSES</b>	<b>RESULTS</b>
First time visitors	79%
Visits over 3-6 days	64%
Camping	68%
Hotels / Resorts	26%
Group Size	> 5 adults
Group Structure	69% Friends and Tours
<b>LAKE MCKENZIE</b>	
<i>A priori</i> plan to visit	75%
First visit	79%
Interest in swimming	95%
<b>SWIMMING</b>	
% swimmers	88%
Less than 30 minutes	76%
<b>LAKE CHARACTERISTICS</b>	
Influence on Enjoyment of Swim...	Average scores (1 = unimportant, 5 = very important)
Clearness, purity of water	4.39
Being in a natural setting	4.08
Water temperature	3.32
Accessibility from camping and amenities	3.19
Number of people present	2.77
Facilities at site	2.27
<b>WATER QUALITY</b>	
Excellent	75%
Added greatly to swim	78%
<b>FACILITIES PROVIDED</b>	
Good	47%
<b>OTHER LAKES</b>	
Visited other lakes	32%
Swum in other lakes	26%
<b>PREFERRED SWIMMING LOCATIONS</b>	
Clear lake	70%
Ocean	24%
Other (stained lakes, streams, pools)	6%
<b>DEMOGRAPHICS</b>	
Sex ratio	51% (male): 49% (female)
Dominant age group	81% between 19-34 years of age
Australian residents	59%
International visitors	41%

Despite the fact that most of the large and accessible lakes on Fraser Island do receive visitors, the clear lakes appear to be the most popular. More than 70% of respondents selected clear lakes as their most preferred swimming location, even when options of the ocean, clear streams, brown stained lakes and swimming pools were offered (Table 3).

Survey respondents were evenly distributed between the two sexes and the majority (> 81%) fell within the ages of 19-34, indicating that Fraser Island attracts a relatively young sub-section of the Australian tourist market (Table 3). The most represented age group was the 25-34 year old bracket, with almost 50% of the survey respondents falling into this category. Only 7% of those surveyed were 45 years or older. Almost two-thirds of the respondents were visitors from overseas, with Australian residents comprising only about one third of those surveyed.

## **Discussion**

Whilst the importance of Lake McKenzie as a focal recreation site on Fraser Island has always been assumed (Sinclair 2000), the data presented herein definitively identifies this lake as one of the most popular and most threatened systems within the World Heritage Area. The growing international awareness of Fraser Island as a tourist destination and the iconic nature of Lake McKenzie are borne out by the fact that the vast majority of survey respondents had planned to visit Lake McKenzie before arriving on the island (Arthington et al. 1990, Steele 1999, Sinclair 2000, Fullerton 2001). In addition, the popularity of and high visitation levels to Lake McKenzie are likely to be further enhanced by the lake's central location on the island (Figure 5, Sinclair 2000). For example, many of the survey respondents were in organised tour groups on day trips, which visit only the most popular sites on the island, including Lake McKenzie.

As expected for a relatively isolated wilderness area, Fraser Island attracts young (< 35 years of age) people seeking wilderness experiences (Newsome et al. 2002), most often in reasonably large groups of up to six adults. Across all age brackets, almost two-thirds of the respondents were overseas visitors to Australia, again highlighting the significance and awareness of the island as an international tourist destination. From a management perspective, these findings need to be taken into consideration, particularly since the continued development of the international tourism market in Australia is likely to see a further increase in the relative contribution of international visitors to Fraser Island in the foreseeable future (Gosselin 1998, Park 1999, Sinclair 2000).

Fraser Island attracts visitors looking for a wilderness experience in a pristine natural setting (Sinclair 2000). The high demand for camping and the support for the relative lack of facilities around Lake McKenzie confirm this generalisation. Furthermore, since camping at undeveloped campsites was the most nominated type of accommodation by survey respondents, the absence of facilities appears to be an attraction more than a discomfort. As such, any moves to further develop infrastructure and to sanitise the island are likely to detract from the 'wilderness' experience that many of the tourists surveyed were seeking (Anon. 1995, Goodrich 1997).

The clear lakes on Fraser Island are obviously some of the most important swimming and recreational sites on the island (Arthington et al. 1990, Tappin 1997, Sinclair 2000). The results presented herein suggest that Lake McKenzie and Lake Birrabeen (the two clear lakes on the island) are likely to be particularly threatened by tourist activities. In addition to their obvious aesthetic appeal, these lakes may suffer as a consequence of their accessibility (see Figure 5), and the high public awareness of them as a consequence of Fraser Island advertising campaigns (personal observation). The unsafe swimming conditions in the ocean around Fraser Island (Sinclair 2000) are also likely to ensure that the lakes receive considerable attention from tourists, particularly throughout the hot summer months.

Despite the high level in interest in swimming in Lake McKenzie expressed by most survey respondents, the length of time spent in the water for most was short (< 30 minutes). This result is likely to be at least partially an artefact of time constraints, particularly for tourists on organised day tours. In addition, the weather on some of the survey days was overcast and windy and the activities of tourists on those days reflected these conditions (personal observation). Despite the short duration of swims, it should be noted that the capacity for tourists to influence the system is not necessarily a function of the time in which they spend engaging with the environment (King & Mace 1974). With regard to urination events in particular, immersion diuresis can occur within minutes of immersion (Sykes 1994, Holt 2000). As such, all swimmers in Lake McKenzie have the potential to adversely affect the system through the introduction of urine and other chemicals, regardless of the duration of their swim (King & Mace 1974).

Because of their appeal, the clear lakes on Fraser Island are likely to continue to receive large numbers of tourists in the future (Arthington et al. 1990, Nelson 1994, Anon. 1995, Wall 1997, Buckley 1998). On the basis of the findings in this study, if the management response to increased visitation levels involves the provision of more facilities, then, the aesthetic appeal of the site to tourists seeking wilderness experiences may be reduced. On the other hand, improved facilities may sanitise the area around Lake McKenzie, thus promoting it to tourists who value the comfort that facilities bring to their holidays. Smart use of the natural environment and the use of unobtrusive buildings for the provision of facilities may ensure that the provision of additional and upgraded

amenities does not interfere with the type of experience that many of the tourists to Fraser Island are seeking. Nevertheless, further promotion of Lake McKenzie may ultimately increase the risk of deleterious impacts from tourist activities on this naturally oligotrophic perched dune lake (Outridge et al. 1989, Arthington et al. 1990).

The long term preservation of the perched dune lakes on Fraser Island is likely to require a balanced approach between the provision of natural resources for recreational purposes and the protection of those resources from impacts caused by over-exploitation from tourism (Buckley & Pannell 1990, Glick & Murr 1997). At present there is very little scientific information on which to base such a management strategy, although preventative measures already in place, particularly with regard to the regulation of sunscreen and detergent inputs in lakes, are a step in the right direction. In the meantime, the appeal of Fraser Island as a tourist destination will continue to increase and the subsequent increase in tourist pressure is likely to require the adoption of strict regulations, as is the case in some of the extremely popular National Parks in the United States (Anon. 1995, Goodrich 1997, Honey 1999). Capping the number of visitors on Fraser Island at any one time and switching between alternate camping areas are a couple of the mechanisms currently being employed to mitigate the potential impacts of growing tourism pressures in wilderness areas (Glick & Murr 1997, Wang & Miko 1997). For the potentially fragile dune lakes on Fraser Island, management strategies which regulate swimming activities as well as the number of visitors in particular catchments may offer the best approach to ensuring their long-term preservation.

## *Chapter 4*

# **The Potential Threat Of Tourism On Dune Lakes On Fraser Island: Analyses of Impacts on Nutrient and Chlorophyll A Concentrations**

## **Introduction**

Increasing demand for natural wilderness experiences by tourists places pressure on some of our more popular National Parks and World Heritage Areas (Leung & Marion 2000, Newsome et al. 2002). Numerous studies have investigated the direct physical impacts of tourist activities in fragile environments, particularly through the trampling of vegetation (Liddle & Scorgie 1980, Whinam & Chilcott 1999, Monz 2002). In addition, there is increasing evidence to suggest that tourists can also alter the chemical nature of the environments they visit (King & Mace 1974, Butler et al. 1996), particularly in oligotrophic aquatic systems where re-suspension and/or addition of nutrients can have substantial biological responses (Dodds & Prisco 1990, Butler et al. 1996, Burns & Schallenberg 1998). For example, Butler et al. (1996) found unnaturally high nutrient concentrations and algal biomass in rock pool swimming holes of pristine streams in North Queensland. These unnaturally high concentrations were attributed to the activities of tourists, most likely via sediment re-suspension and urine inputs (Butler et al. 1996). Whilst the long-term consequences of these actions are unknown, evidence from other oligotrophic systems suggests that they may lead to increased primary productivity and/or the proliferation of undesirable algal communities (Welch, Jacoby, Horner & Seeley 1988, Hawes & Smith 1993, Havens, East, Meeker, Davis & Steinman 1996b).

Several authors have suggested that the oligotrophic perched dune lakes on Fraser Island may be particularly susceptible to adverse ecological consequences following nutrient additions from tourist sources (Bowling 1988, Outridge et al. 1989, Arthington et al. 1990). As Outridge et al. (1989) and Arthington et al. (1990) noted the closed hydrology of perched dune lakes ensures that added nutrients will accumulate in these systems over time. Furthermore, with ambient total phosphorus and chlorophyll a concentrations rarely exceeding 5 µg/L and 1 µg/L respectively (Arthington et al. 1990), the likelihood of undesirable outcomes following ongoing nutrient additions in these systems is high (Outridge et al. 1989, Arthington et al. 1990, Butler et al. 1996). Importantly, given that visitor numbers have risen by almost 300% since Fraser Island was granted World Heritage Status in 1992 (Anon 1998, UNESCO 2001), the threats that tourists pose to perched dune lakes have similarly increased (Sinclair 2000, Fullerton 2001).

The work of Outridge et al. (1989) also suggests that the characteristic algal flora in these oligotrophic dune lake systems is well equipped to respond to additions of nutrients. Together these factors suggest that nutrient additions in perched dune lakes are likely to lead to rapid increases in algal biomass (Outridge et al. 1989, Arthington et al. 1990).

In view of the threats that tourists may have on the health of the dune lakes on Fraser Island, this component of the study was undertaken to address the following questions:

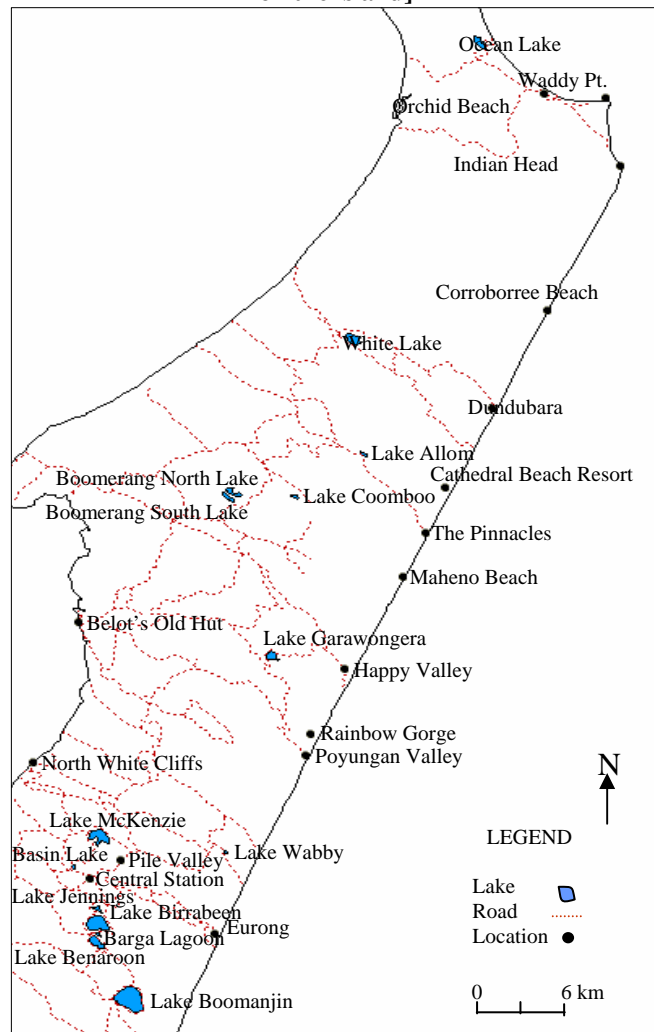
1. Which lakes are potentially most under threat from tourist activities?
2. Does the low trophic status and high clarity of some lakes make them particularly susceptible to adverse impacts from tourism?
3. How much of the observed variation in trophic status of lakes can be explained by tourist visitation pressure?
4. Is there any indication that trophic status, measured by nutrient and chlorophyll a concentrations, has increased since the study by Arthington et al. (1990)?

## **Method**

### ***Lake Selection***

In February 1999, 15 Fraser Island dune lakes were chosen for this study. Lakes were selected on the basis of their representation of the diversity of dune lakes on Fraser Island as well as their perceived visitation levels. In addition, many of the lakes chosen had been investigated in previous studies (Bayly 1964, Bayly et al. 1975, Arthington et al. 1986, Bowling 1988, Arthington et al. 1990). Two window lakes (Lake Wabby and Ocean Lake) and 13 perched lakes (Lake Boomanjin, Lake Benaroon, Barga Lagoon, Lake Birrabeen, Lake Jennings, Lake McKenzie, Basin Lake, Lake Garawongera, Coomboo Lake, Lake Boomerang South, Lake Boomerang North, Lake Allom and White Lake) were selected (Figure 6).

**Figure 6: Map of Fraser Island [insert shows all 15 study lakes, roads, streams and major tourist locations on the island]**



***Tourist Pressure Index***

To determine the relative pressure of tourism on each of the 15 study lakes, factors relating to accessibility, publicity and the provision of facilities were used to calculate a Tourist Pressure Index (TPI) as follows:

$$TPI = \{(P + R + A) / [(lowest\ of\ B\ or\ S) + C + T]\} \times 100$$

Where:

- B** = distance to nearest barge landing (kms)
- S** = distance to nearest settlement (kms)
- C** = distance to nearest camping area (kms)
- T** = distance to nearest toilet facilities (kms)
- P** = publicity surrounding site (0 = unknown, 1 = on postcards, QNPWS flyers etc, 2 = well known)
- R** = road quality – relates to ease of travel (0 = closed road, 1 = used road, 2 = scenic drive)
- A** = accessibility of lake to parking facilities (0 = no track, 0.5 = long track, 1 = medium length track, 2 = short track)

Since day visits to lakes by tourists are strongly influenced by the ease of access from the mainland (access via barge only) or from settlements on the island (4WD vehicular access only), the lower of **B** or **S** was used to calculate the TPI score for each lake. **S** was primarily used for the lakes in the northern part of the island, where distances to the nearest barge landings suggest that day-trips are logistically prohibited.

High TPI scores relate to higher potential pressure from tourism. Low values for **B** (or **S**), **C** and **T** are likely to attract tourists to a lake, as they represent the accessibility and comfort afforded to tourists whilst at the lake. In contrast, low values for **P**, **R** and **A** would mitigate potential impacts, as each has the potential to reduce tourist motivations to visit lakes.



### ***Limnological Investigations***

From February 15 to March 3 1999, a limnological survey was conducted to determine baseline physical and chemical measurements, nutrient concentrations and chlorophyll a concentrations in each of the 15 lakes. Importantly, this investigation aimed to assess whether lake trophic status (as determined from nutrient and chlorophyll a concentrations) could be explained by TPI scores.

### ***Physical and Chemical Parameters***

Dissolved oxygen, conductivity and pH were measured using a Greenspan® meter and probes in each of the study lakes. All measurements were taken at a depth of 1 metre in two haphazardly selected epilimnetic sites.

### ***Nutrient and Tannin Concentrations***

All water samples were collected in reverse osmosis washed polyethylene bottles. Unfiltered samples were taken for samples of total nitrogen (TN) and total phosphorus (TP) concentrations, whilst water samples filtered through a 0.45 µm filter were taken to assess concentrations of ammonium (NH<sub>4</sub><sup>+</sup>) and nitrogen oxides (NO<sub>x</sub><sup>-</sup>). In addition to nutrient analyses, unfiltered water samples were collected from each lake for analysis of tannin concentrations (µg/L). In all instances, samples were immediately placed on ice, frozen within 5 hours and transported to the Scientific Services division of Queensland Health for analysis.

### ***Chlorophyll A Concentrations***

A hand pump and filter apparatus was used to filter two replicate water samples through 0.7 µm glass-fibre filter papers at both epilimnetic sites. Each filter paper was stored in a centrifuge tube wrapped in aluminium foil and samples were immediately put on ice and frozen.

Analysis of chlorophyll a concentrations followed the standard methods described for aquatic samples (Parsons, Maita & Lalli 1984). Chlorophyll a on filter papers was extracted overnight at 4°C in 90% acetone, sonicated for 1 minute and centrifuged for 3 minutes at 3000g. Sample absorbances were measured using a 'Shimadzu UV-1601' spectrophotometer with acidification for phaeophyton corrections. All chlorophyll a concentrations are expressed as µg/L and were standardised according to the volume of lake water filtered to attain the sample.

### ***Multivariate Analysis***

Physical and chemical attributes of lakes, including dissolved oxygen, conductivity, pH, nutrient concentrations, tannin concentrations and chlorophyll a concentrations were ordinated using multi-dimensional scaling (PATN; Belbin 1995). The raw data matrix was standardised to remove the bias of zeros and very large numbers in the data set. The data were then converted into an association matrix using the Bray-Curtis measure of dissimilarity (Bray & Curtis 1957). Semi-Strong-Hybrid (SSH) multidimensional scaling was used to generate the ordination plots from the matrix (Belbin 1991). Vectors representing the subset of variables which best describe the pattern displayed in the ordination plot were determined using the Principal Axis Correlation (PCC) procedure and the significance levels for each of the vectors were calculated using a Monte Carlo Randomisation Test (Manly 1991). Only the vectors that were found to contribute significantly (p < 0.05) to the patterns in the ordination plot are presented.

### ***Total Phosphorus – Chlorophyll A Relationship***

Arthington et al. (1990) found a strong positive linear relationship between log total phosphorus and log chlorophyll a concentrations, which enabled the prediction of chlorophyll a concentrations in response to anticipated increases in total phosphorus concentrations. For the current data set, regressions of total phosphorus versus chlorophyll a concentrations were conducted to determine whether there has been a shift in the relationship observed by Arthington et al. (1990).

### ***Comparative Analyses***

Total phosphorus and chlorophyll a concentrations from the current data set were compared against those of Arthington et al. (1990) for the five lakes common to both studies (Wabby, Ocean, McKenzie, Birrabeen and Jennings). Concentrations were compared statistically using the novel ANOVA model designed by McKone and Lively (1993), enabling a powerful analysis of temporal changes within lakes rather than focussing on differences between lakes.

## Results

### *Tourist Pressure Index*

TPI scores suggested that the clear lakes, Lake McKenzie and Lake Birrabeen, and the small stained lake, Lake Allom, are currently under the most pressure from tourist activities (Table 4). With TPI scores of 61.2, 34.3 and 35.7 respectively, these lakes represent some of the most accessible and heavily visited systems on the island.

The other lakes with relatively high TPI scores were Ocean Lake and Lakes Jennings, Boomanjin, and Garawongera. The higher scores for most of the lakes from the central series (see Figure 6) reflect the density of tourist activities between Central Station and Lake Boomanjin. In contrast, most of the lakes in the northern section of the island had relatively low TPI scores (Table 4), with the exception of Lake Allom (which has both toilets and camping facilities).

**Table 4: Tourist Pressure Index (TPI) scores and ranks for 15 Fraser Island dune lakes (higher scores – lower ranks – indicate greater pressure and potential for adverse impacts from tourist activities). Lakes presented from south to north (Figure 6)**

Lake	TPI Score	Rank (Highest to Lowest)
Boomanjin	21.0	6
Benaroon	14.3	11
Barga	14.4	10
Birrabeen	34.3	3
Jennings	22.9	4
Basin	17.9	8
McKenzie	61.2	1
Wabby	15.7	9
Garawongera	19.0	7
Boomerang South	11.5	12
Boomerang North	6.9	13
Coomboo	6.0	14
Allom	35.7	2
White	2.6	15
Ocean	21.2	5

$$TPI = (P + R + A) / [(lowest\ of\ B\ or\ S) + C + T] \times 100$$

### *Physicochemical Parameters*

Values for tannin concentrations, pH, conductivity and dissolved oxygen fell within the ranges expected for perched dune lakes on Fraser Island. All of the perched lakes were acidic, with pH values ranging from 4.15 in Barga Lagoon to 5.34 in Lake Allom. In contrast, the two window lakes (Ocean Lake and Lake Wabby) had relatively neutral pH values of 6.81 and 6.72, respectively (Table 5).

Ocean Lake (343.7  $\mu$ S/cm) and Lake Wabby (155.6  $\mu$ S/cm) had substantially higher conductivity values than the perched dune lakes (range from 54.7  $\mu$ S/cm in Barga Lagoon to 107.2  $\mu$ S/cm in Lake Boomanjin). On the basis of surface dissolved oxygen concentrations (ranging from 9.60 in Ocean Lake to 11.37 in Lake Allom), all of the lakes studied were at or near saturation when sampled in February 1999.

**Table 5: Mean ( $\pm$  s.e.) values for pH, dissolved oxygen, conductivity, tannin concentrations and secchi depths in 15 Fraser Island dune lakes, sampled February – March 1999**

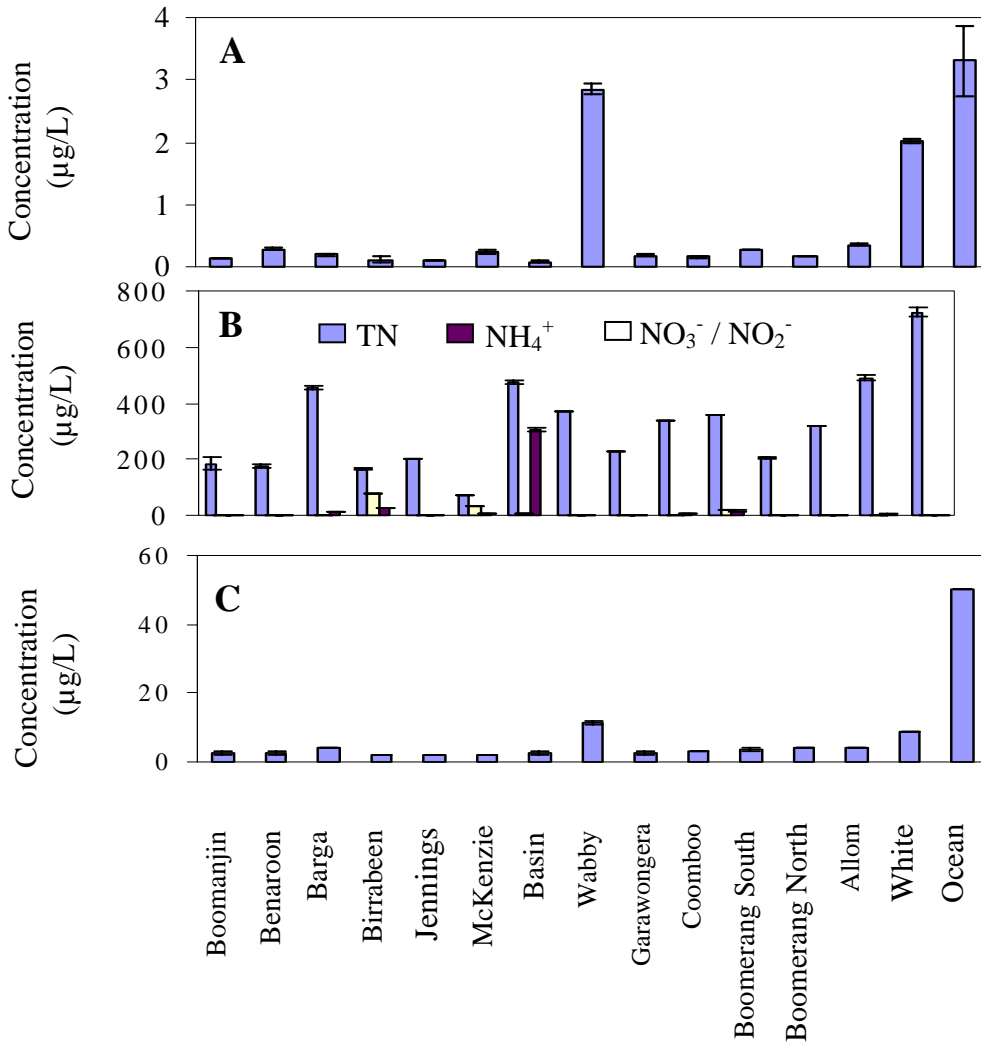
Lake	pH	Cond. ( $\mu$ S $cm^{-1}$ )	Temp ( $^{\circ}C$ )	DO ( $mg\ l^{-1}$ )	Tannins ( $\mu g\ l^{-1}$ )	Secchi Depth (m)
Boomanjin	4.60 (0.05)	107.2 (1.8)	29.3 (0.01)	10.6 (0.00)	1650 (50)	1.48 (0.02)
Benaroon	4.56 (0.03)	84.3 (0.1)	29.0 (0.04)	10.5 (0.02)	500 (0)	2.92 (0.16)
Barga	4.15 (0.01)	54.9 (1.8)	30.4 (0.8)	11.2 (0.2)	4900 (200)	0.60 (0.05)
Birrabeen	4.64 (0.02)	91.8 (0.4)	29.1 (0.1)	10.5 (0.01)	100 (0)	5.83 (1.13)
Jennings	4.44 (0.01)	78.6 (0.1)	29.8 (0.04)	10.7 (0.01)	1450 (50)	2.23 (0.12)
Basin	5.00 (0.01)	63.7 (0.2)	28.8 (0.4)	10.6 (0.1)	200 (0)	4.73 (0.43)
McKenzie	4.82 (0.02)	91.3 (0.1)	27.9 (0.2)	10.1 (0.02)	100 (0)	8.60 (0.00)
Wabby	6.72 (0.19)	155.6 (0.03)	28.2 (0.05)	10.2 (0.02)	200 (0)	1.53 (0.08)
Garawongera	5.22 (0.03)	73.0 (0.3)	30.0 (0.7)	10.9 (0.3)	1000 (0)	3.16 (0.04)
Boomerang Sth	4.67 (0.01)	65.4 (0.6)	29.2 (0.04)	10.7 (0.1)	2300 (50)	0.80 (0.03)
Boomerang Nth	4.61 (0.00)	98.7 (0.3)	29.7 (0.3)	10.7 (0.01)	750 (0)	1.73 (0.05)
Coomboo	4.55 (0.00)	55.9 (0.2)	29.9 (0.02)	10.6 (0.2)	2700 (50)	1.41 (0.02)
Allom	5.34 (0.02)	64.9 (1.2)	31.1 (0.5)	11.4 (0.1)	1100 (100)	2.15 (0.20)
White	4.72 (0.00)	101.9 (0.6)	27.1 (0.03)	9.8 (0.01)	800 (0)	1.63 (0.03)
Ocean	6.81 (0.01)	343.7 (0.4)	26.6 (0.1)	9.6 (0.04)	1000 (0)	0.88 (0.02)

**Water Quality Parameters**

*Total Phosphorus*

Total phosphorus concentrations were generally below 5 µg/L (Figure 7), suggesting that the majority of the systems were oligotrophic. Only White Lake and the two window lakes, Wabby and Ocean, had total phosphorus concentrations approaching those more typical of mesotrophic conditions (> 10 µg/L).

**Figure 7: Mean nutrient and chlorophyll a concentrations (± s.e.) from 15 Fraser Island lakes in February 1999: A = TP; B = TN, NH<sub>4</sub><sup>+</sup> and NO<sub>x</sub>; C = chlorophyll a**



*Total Nitrogen, Ammonium & Nitrogen Oxides*

Some of the lowest ammonium and nitrogen oxide concentrations recorded were for the water-table window lakes (Ocean and Wabby), despite their high total nitrogen concentrations (Figure 7). In contrast, the two clear perched lakes (McKenzie and Birrabeen) had relatively high levels of ammonium and nitrogen oxides (up to an order of magnitude greater than most of the other perched lakes).

*Chlorophyll A*

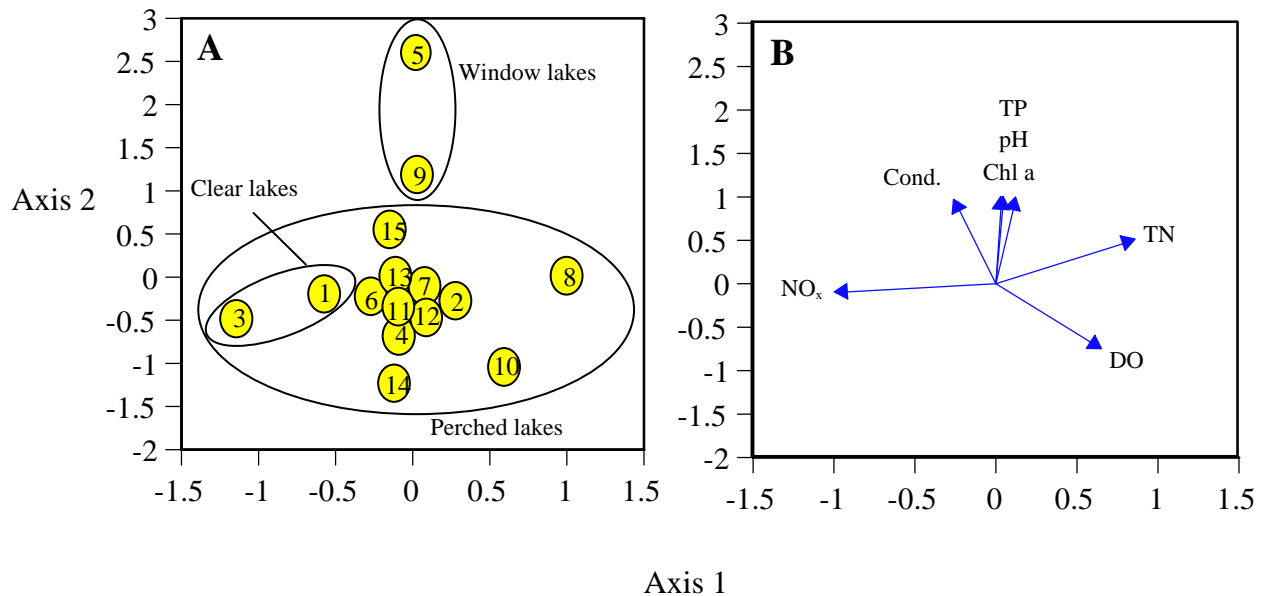
Chlorophyll a concentrations were an order of magnitude higher in the window lakes (Ocean and Wabby) than in the perched dune lakes (Figure 7). Concentrations generally fell within the range from 0.08 µg/L (Lake McKenzie) to 0.35 µg/L (Lake Allom) and across all lakes there was a strong (R<sup>2</sup>=0.84) positive relationship between epilimnetic total phosphorus and chlorophyll a concentrations.

### Multivariate Analysis

The window lakes (Wabby [9] and Ocean [5]) were separated from the perched dune lakes on Axis 2 in ordination space (Figure 8). This separation was driven by the higher total phosphorus concentrations, higher chlorophyll a concentrations, higher pH's and higher conductivity of the window lakes. In addition, the perched dune lakes showed considerable variation along Axis 1, associated with TN concentration (Figure 8). The clear lakes (McKenzie [1] and Birrabeen [3]) were distinguished by their high NO<sub>x</sub> concentrations (Figure 8).

On the basis of the parameters used in the analysis, there was very little difference between most of the perched dune lakes sampled. However, Barga Lagoon [10] was slightly removed from the main cluster due to comparatively low dissolved oxygen concentrations and White Lake [15] sits closest to the window lakes in two dimensional ordination spaces owing to its comparatively high total nitrogen, total phosphorus and chlorophyll a concentrations (Figure 8). Basin Lake [8] also sits removed from the main cluster, due to its high total nitrogen (and ammonium) concentrations (Figure 8).

**Figure 8: (A) Ordination plot of 15 Fraser Island dune lakes based on nutrient, chlorophyll a and physicochemical variables; (B) Vectors describing the pattern in 'A' (stress = 0.0141)**



(A) Lakes are numbered according to their TPI Scores as Follows: 1. Lake McKenzie, 2. Lake Allom, 3. Lake Birrabeen, 4. Lake Jennings, 5. Ocean Lake, 6. Lake Boomanjin, 7. Lake Garawongera, 8. Basin Lake, 9. Lake Wabby, 10. Barga Lagoon, 11. Lake Benaroon, 12. Boomerang Lake South, 13. Boomerang Lake North, 14. Lake Coomboo, 15. White Lake.

### Comparative Analyses – February 1990 versus February 1999

#### Total Phosphorus

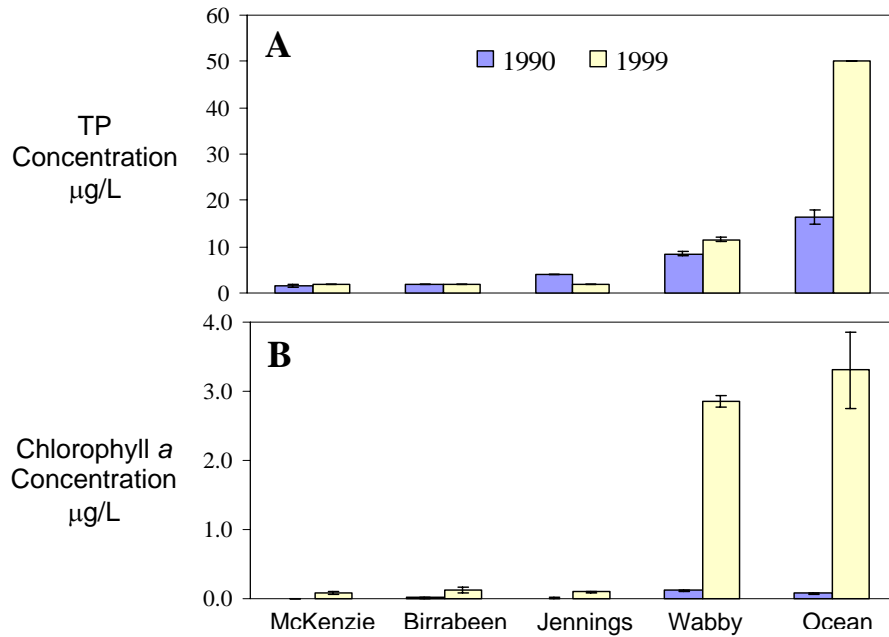
Total phosphorus concentrations in the 5 Fraser Island dune lakes sampled in February 1999 and February 1990 (Arthington et al. 1990), showed significant yet lake-specific temporal variability ( $p=0.0001$ , Figure 9).

Total phosphorus concentrations were higher in the February 1999 samples than in the February 1990 samples in the two water-table window lakes (Ocean  $p=0.0066$ ; Wabby  $p=0.0537$ ). However, this was not the case in the perched dune lakes, where total phosphorus concentrations in Lake McKenzie and Lake Birrabeen showed no change, whilst those in Lake Jennings fell from 4  $\mu\text{g/L}$  in 1990, to 2  $\mu\text{g/L}$  in 1999 ( $p=0.0001$ ).

#### Chlorophyll A

Chlorophyll a concentrations were at least an order of magnitude higher in 1999 than in 1990 in all five lakes (Figure 9).

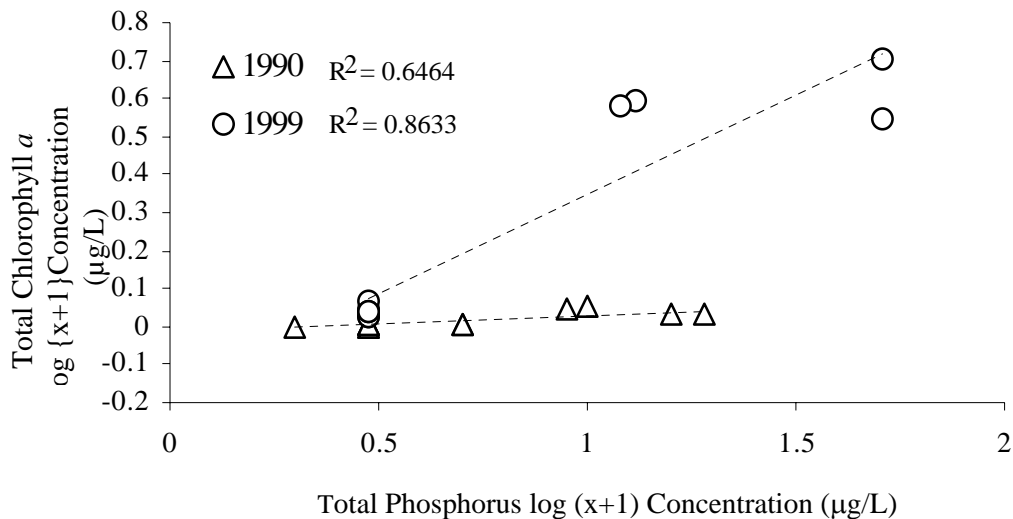
**Figure 9: Mean ( $\pm$  s.e.) total phosphorus (A) and chlorophyll a concentrations (B) in five Fraser Island dune lakes in February 1990 (Arthington et al. 1990) and February 1999 (current study)**



*Total Phosphorus Versus Chlorophyll A*

A positive relationship was observed between  $\log(x+1)$  total phosphorus and  $\log(x+1)$  chlorophyll a concentrations in both the 1990 (data from Arthington et al. 1990) and 1999 sample periods (Figure 10). However, statistical comparisons of the slopes of the 1990 and 1999 data sets found that they were significantly different from each other ( $p < 0.01$ ). This difference is most likely due to the elevated chlorophyll a concentrations in Lake Wabby and Ocean Lake in 1999 and the subsequent influence they have over the slope of the regression line.

**Figure 10: Total phosphorus-chlorophyll a relationships in five Fraser Island dune lakes in February 1990 (data from Arthington et al. 1990) and February 1999 (current study)**



## **Discussion**

### **Which Lakes are Most Threatened by Excessive Tourist Use?**

TPI scores calculated for the 15 dune lakes examined in this study suggest that the clear lakes on Fraser Island are some of the most threatened by tourist activities. These results support the findings from the tourist surveys conducted at Lake McKenzie, where 70% of the tourists censused identified clear lakes as their preferred swimming location.

In addition to highlighting the focus of tourist attention on these systems, this result suggests that the TPI index developed here adequately predicts the systems that are most likely to be threatened by tourism. Furthermore, the complementarity of the results of TPI analyses and those of tourist surveys suggests that the TPI model adequately represents some of the most influential decision-making variables (such as accessibility, the provision of amenities and the value of wilderness experiences) for tourists visiting Fraser Island.

TPI scores for Lake McKenzie, Lake Allom, Lake Birrabeen, Lake Jennings, Lake Boomanjin, Ocean Lake and Basin Lake suggest that these systems all warrant close attention to ensure that tourist activities are monitored and that impacts are minimised. Interestingly, only one of these lakes (Ocean Lake) is in the northern half of the island and this result reflects the increasing difficulties associated with accessing sites in the north. Future TPI scores will consequently have to be updated to reflect the consequences of some of the more recent road closures in the northern part of the island (personal observation). Nevertheless, the bias towards lakes in the central part of Fraser Island highlights the importance of site accessibility and camping facilities (Figure 2).

### **What is the Relationship between TPI Scores & Lake Vulnerability?**

Nutrient levels in most of the dune lakes examined fell within the expected ranges for oligotrophic systems (Budy, Luecke & Wurtsbaugh 1998, Schallenberg & Burns 2001) and were consistent with recent monitoring findings (Hockings 1999). Only three lakes (Ocean, Wabby and White) had total phosphorus concentrations above the suggested threshold concentration (5 µg/L) for protection of these lakes (Arthington et al. 1990). For the two window lakes, Lake Wabby and Ocean Lake, phosphorus concentrations were expected to be higher than those in the perched dune lakes, owing to their connection to the comparatively nutrient-rich regional aquifer (Bowling 1988, Arthington et al. 1990). For the perched White Lake, high total phosphorus concentrations may arise as a consequence of the lake's shallow depth and exposure to the prevailing south-easterly winds (Hockings 1999). Together, these characteristics can lead to substantial sediment (and therefore nutrient) re-suspension (Luettich, Harleman & Somlyody 1990, Bailey & Hamilton 1997, Hockings 1999).

The comparatively high nitrogen oxide concentrations reported here for Lake McKenzie and Lake Birrabeen suggest that these clear lakes are showing signs of being somewhat chemically distinct from the organically stained perched lakes studied. Whilst it is unknown as to whether or not tourists are responsible for these unusual conditions, the high TPI scores of these systems and the known preference of tourists to swim in these clear lakes (based on tourist survey results) indicate that tourists may contribute to these elevated NO<sub>x</sub> levels.

In contrast to Lakes McKenzie and Birrabeen, the exceptionally high ammonium concentrations in Basin Lake are unlikely to be attributable to the consequences of additions purely from tourist sources. Given the approximated volume of this lake, in excess of 32 million urination episodes from tourists would have been required to attain the measured ammonium concentrations in this system. Nevertheless, the relatively high TPI score for this system, coupled with the lack of toilet facilities and recent increases in visitation levels, suggests that tourists are likely to be influencing nutrient inputs into this lake (Butler et al. 1996).

### **Changes in Lake Trophic Status Since 1990**

The results of comparisons of current and historical (Arthington et al. 1990) nutrient and chlorophyll a data in five lakes highlight some of the difficulties associated with monitoring and detecting changes in freshwater systems (Thomas & Eaton 1996, McCormick & Stevenson 1998, Vis, Hudon, Cattaneo & Pinel-Alloul 1998). On the basis of total phosphorus concentrations, the window lakes (Ocean and Wabby) have both shown an increase in trophic status over time (Figure 9). In contrast, phosphorus concentrations in the three perched dune lakes (McKenzie, Birrabeen and Jennings) showed no signs of increasing with time (and concentrations fell significantly in Lake Jennings – Figure 9).

Whilst the high TPI scores for Ocean Lake and Lake Wabby indicate that tourists may represent a significant source of nutrient additions, it is equally likely that other biotic and abiotic factors are responsible for these increases in trophic status between 1990 and 1999 (Henrikson, Nyman, Oscarson & Stenson 1980, Hockings 1999, Kopacek, Stuchlik, Straskrabova & Psenakova 2000, Havens et al. 2001). Since both of these water-table window lakes are connected to the regional aquifer, the higher ambient nutrient concentrations may be the result of nutrient additions to the aquifer from elsewhere (James 1984, Arthington et al. 1990, Hockings 1999). Furthermore, anecdotal evidence suggests that cormorants and other waterbirds, which roost in the riparian vegetation that fringes Ocean Lake, may add substantial quantities of nutrients to the water column

through their faeces (Pettigrew, Hann & Goldsborough 1998, Hockings 1999). Hockings (1999) noted in his report that the likelihood of substantial and ongoing nutrient additions from these roosting bird communities far outweighs the potential nutrient additions from tourist sources for this lake.

For Lake Wabby, increased trophic status is most likely attributable to a substantial reduction in lake volume between sampling periods. As Arthington et al. (1986) noted, this lake has been partially in-filled by a large mobile sand dune. Since the volume of Lake Wabby was reduced by 43% between 1975 and 1984, due to of a maximum rate of dune advancement of around 5 m year<sup>-1</sup> (Arthington et al. 1986), it is highly likely that changes in volume have contributed to the increased phosphorus concentrations measured in this system in the current study.

Despite the variability in total phosphorus concentrations over time, all five lakes exhibited substantial increases in chlorophyll a concentrations between the 1990 and 1999 sampling periods. This breakdown of the relationship between phosphorus and chlorophyll a concentrations is likely to be a consequence of rapid nutrient assimilation by algal flora (Thomas & Eaton 1996). As numerous researchers have noted, algae in oligotrophic systems often assimilated added nutrients rapidly, to the point at which the detection of added nutrients in the water column is extremely difficult (Dodds & Priscu 1989, 1990; Dodds et al. 1991, Dodds 1995, Costanzo, O'Donohue, Dennison, Loneragan & Thomas 2001). Nevertheless, since chlorophyll a is widely used as a biological indicator of changes in nutrient concentrations in aquatic systems (Whitton & Kelly 1995, Pan, Stevenson, Hill, Herlihy & Collins 1996, Kelly 1998, Kelly & Whitton 1998), these increased chlorophyll a levels suggest that nutrient additions are likely to have occurred in these systems.

Whilst changes in the relationship between total phosphorus and chlorophyll a concentrations cannot be solely attributed to the activities of tourists (Havens 1999), contemporary increases in total phosphorus concentrations in Lakes Ocean and Wabby, and increased chlorophyll a concentrations in all five lakes, indicate that they are becoming more productive (Schindler 1978, Carpenter & Kitchell 1987). Monitoring should consequently focus on the rate at which changes in production (as identified by chlorophyll a concentrations) and trophic status are occurring in these systems, rather than on ambient nutrient concentrations.

## *Chapter 5*

# **Phytoplankton And Periphyton Responses To Tourist Nutrient Additions In Perched Dune Lakes On Fraser Island**

## **Introduction**

Tourists can adversely affect water quality in aquatic ecosystems, both directly through the addition of nutrients and indirectly through sediment re-suspension (Arthington et al. 1989, Arthington et al. 1990, Butler et al. 1996, Proulx et al. 1996). In oligotrophic systems, where increases in nutrient concentrations can artificially inflate primary production beyond the regulatory control of grazer communities (Cyr & Pace 1992, Hansen, Anderson & Jensen 1997, Blomqvist 2001), the consequences of these effects can lead to increased algal production and biomass (Ganf & Oliver 1982, Smith 1986). In some instances, this proliferation of algae can result in blooms of noxious forms (cyanobacteria) which can have both undesirable ecological and sociological consequences (Fong, Donohue & Zedler 1993, Boon, Bunn, Green & Shiel 1994, Gehrke & Harris 1994).

Whilst direct additions of nutrients from tourist sources may represent relatively small increases in absolute nutrient concentrations (Strasinger 1994), the well-documented responsiveness of oligotrophic systems to nutrients suggests that repeated additions may have considerable environmental consequences (Shortreed & Stockner 1990).

Since the oligotrophic perched dune lakes form the focus of swimming and recreation activities on Fraser Island (as established in earlier sections of this document) deleterious impacts may occur if visitation to these systems remains unregulated (Outridge et al. 1989, Arthington et al. 1990). To date, there have been very few studies investigating the effects of tourists on the ecology of the perched dune lakes on Fraser Island (Arthington et al. 1990, Hockings 1999). However, Arthington et al. (1989, 1990) and Outridge et al. (1989) examined the impacts of tourists on dune lakes in the nearby Cooloolo Region and found that increased tourist visitation was most probably responsible for their shift from oligotrophic to mesotrophic conditions. Furthermore, Outridge et al. (1989) postulated that dune lakes with phytoplankton communities dominated by atmospheric nitrogen-fixing cyanobacteria might be particularly responsive to phosphorus additions (McQueen & Lean 1987, Levine & Schindler 1999).

In addition to the inherent problems associated with trying to measure the effects of repetitive yet miniscule nutrient additions, it is important to acknowledge that the activities of tourists are spatially explicit (Liddle & Scorgie 1980, Underwood 1996). As Liddle and Scorgie (1980) noted, impacts from tourist activities are most likely to be focussed on access areas within the littoral zone rather than being spread throughout a lake. As a result, monitoring efforts aimed at measuring impacts from tourists should focus on the littoral zone rather than on the epilimnion (where measures of nutrient and chlorophyll a concentrations have been taken traditionally - Hansson 1988, 1990; Smoot, Langworthy, Levy & Findlay 1998). Furthermore, since beds of aquatic macrophytes are often more productive than phytoplankton communities in shallow lakes like those on Fraser Island, nutrient additions are likely to elicit strong growth responses from primary producers within these shallow shoreline reaches (Loeb, Reuter & Goldman 1983, Harrison & Hildrew 1998, Havens, East, Rodusky & Sharfstein 1999, Nozaki 2001).

In light of the threats that tourism poses on littoral zone water quality and primary production, this component of the study aimed to address the following questions:

1. Can tourist activities influence nutrient status and algal growth (phytoplankton and periphyton) on a small spatial (within lake) scale in the littoral zones of perched dune lakes on Fraser Island?
2. Which nutrients, if any, limit the production of littoral zone phytoplankton and periphyton communities in perched dune lakes on Fraser Island?

## **Materials & Method**

### **Lake Selection**

In 1999, five of the most popular perched dune lakes on Fraser Island (for recreation) were selected to examine the impact of tourists on nutrient and chlorophyll a (phytoplankton and periphyton) concentrations in the littoral zone. Both clear and tannin-stained systems were chosen, since dissolved organic carbon (and subsequent light attenuation) can influence the responses of systems to nutrient additions (Vinebrooke & Leavitt 1998, Williamson, Morris, Pace & Olson 1999, Klug & Cottingham 2001). Three of the lakes chosen (Basin, McKenzie and Birrabeen) were relatively clear (with very low tannin concentrations) and two (Jennings and Boomanjin) were heavily stained with tannins (see Figure 6). In each lake, sites frequented by tourists (disturbed sites) and those rarely visited by tourists (reference sites) were identified to enable within-lake analyses of the



impacts of tourists on nutrient and chlorophyll a concentrations. Samples were collected on three occasions: December 1999, February 2000 and March 2000.

### **Ambient Nutrients & Phytoplankton Chlorophyll A**

Littoral zone water samples were collected and analysed for nutrient and chlorophyll a concentrations in the same way as discussed in earlier sections.

### **Periphyton Chlorophyll A**

At each sampling site, the stems of three reeds (*Lepironia articulata* - Cyperaceae) were collected from the littoral zone at a depth of 1 metre. Reeds were carefully cut near the base and the submerged sections of the reeds (30 – 70 cm long) were placed in individually labelled zip-lock bags for storage. Samples were stored in the dark on ice, before being frozen for transportation back to the laboratory.

In the laboratory, periphyton was carefully scraped from individual reed stems into glass beakers using a fine-toothed brush. The resultant algal suspensions were diluted up to 200ml with distilled water and then filtered onto 0.7 µm glass fibre filter papers. Samples were thereafter processed according to the methods outlined above for phytoplankton chlorophyll a.

### **Artificial Reeds**

In November 1999, artificial 'reeds' were deployed in each lake to determine the accrual of periphyton biomass over the course of the 1999-2000 summer. The one metre long artificial reeds were constructed from inert Ultra-High Molecular Weight (UHMW) polyethylene rods and covered with 100 µm mesh sleeves (fastened using cable ties) to provide a substrate for algal attachment. In all cases, rods were deployed in approximately 1.5 metres of water in the littoral zone and spaced at least 5 metres apart, along a stretch of 50 metres of shoreline. Rods were concealed amongst beds of the reed *Lepironia articulata*, to ensure that they were not visible to tourists.

After six weeks of *in situ* incubation, mesh sleeves were carefully removed from the rods. Sleeves were placed in individually labelled zip-lock bags and stored in the dark on ice. In the laboratory, attached algal material was carefully removed from the mesh sleeves using a scalpel blade and fine toothed brush. Analysis of chlorophyll a concentrations per unit area of mesh sleeve followed the methods described earlier for periphyton chlorophyll a.

### **Algal Bioassays of Nutrient Limitation**

During the 2000-2001 summer, experimental algal bioassays were conducted in the reference sites of each lake to determine which (if any) nutrients limited algal growth. Bioassays (for both phytoplankton and periphyton) presented algal communities with nutrient additions in four experimental treatments. Nutrients were added at concentrations determined on the basis of known maximum concentrations in perched lake systems (Outridge et al. 1989, Arthington et al. 1990). The control treatment (C) had no nutrients added, the nitrogen treatment (N) had 50 µg/L of ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>) added, the phosphorus treatment (P) had 10 µg/L of sodium phosphate (Na<sub>2</sub>HPO<sub>4</sub>) added and the nitrogen + phosphorus treatment (N+P) had additions of both the ammonium nitrate and sodium phosphate (NH<sub>4</sub>NO<sub>3</sub> + Na<sub>2</sub>HPO<sub>4</sub>).

Phytoplankton bioassays were conducted in early summer (November 2000). In each lake, twenty 6-litre carboys (clear plastic containers) were filled with 5 litres of unfiltered lake water and randomly assigned to one of the four nutrient treatments. Once spiked and sealed, carboys were floated in approximately 1 metre of water in the littoral zone. After seven days of *in situ* incubation, carboys were collected and samples were obtained for chlorophyll a analyses by filtering measured quantities of carboy contents onto 0.7 µm glass fibre filter papers using a hand pump and filter apparatus.

Periphyton bioassays were undertaken using nutrient diffusing substrates. Small (300 ml) polyvinyl chloride pots were used to contain nutrient-enriched agar. Five replicate pots were randomly assigned to each of the four experimental treatments (C, N, P and N+P). Pots were filled with a mixture of 2% bacteriological agar (Oxoid No. 1) and nutrients at the same concentrations used in the phytoplankton bioassays (see above). The aperture of each pot was covered with fine (100µm) mesh to facilitate algal attachment and sampling (Mosisch, Bunn, Davies & Marshall 1999). Each mesh-covered agar pot was individually wrapped in plastic wrap and refrigerated prior to transportation and all pots were kept on ice until they were deployed.

In each lake, 25 agar pots were deployed (5C in reference sites and 20 [5C, 5N, 5P and 5N+P] in disturbed sites). Pots were placed at least 1 metre apart and were deployed in five blocks of four, with one replicate from each of the four treatments randomly assigned in each block. Each block ran parallel to the shoreline of the lake and pots were placed in approximately 30 cm of water. Blocks were spaced 5 m apart and the five blocks consequently spanned in excess of 45 metres of the shoreline. The five additional control pots were deployed in disturbed sites to facilitate comparisons of attached algal growth on inert substrates between disturbed and

reference sites. Pots were secured to the lake bottom using large (30 cm) plastic irrigation pegs and were deployed in November 2000 and retrieved in December 2000.

Significant losses of agar from pots deployed in Lake McKenzie and Lake Birrabeen, presumably as a consequence of feeding by turtles (personal observation), meant that the experiment had to be re-run in January 2001. This second experiment used small exclusion cages (20 cm x 20 cm x 20 cm) made out of PVC gardening mesh (mesh diameter 1cm), to inhibit interference by turtles. The cages were secured around the deployed pots using large (30 cm) irrigation pegs.

In both runs, collected mesh lids were placed in individually labelled zip-lock bags and stored on ice in the dark. In the laboratory, the lids were trimmed to 45 cm<sup>2</sup>, to ensure that only the surface area that was in direct contact with the agar-nutrient mix was analysed for chlorophyll a concentrations (Mosisch et al. 1999). Samples were thereafter processed for chlorophyll a using the methods outlined above.

## **Statistical Analyses**

### *Ambient Nutrients & Chlorophyll A Concentrations*

All monitoring data (nutrient and chlorophyll a concentrations) were analysed using the nested ANOVA of McKone and Lively (1993) that was specifically designed to enable the detection of within-site differences across multiple sites. Site (disturbed versus reference) effects within each sampling period (December 1999, February 2000 and March 2000) were consequently analysed separately for each lake, since the primary goal was to detect differences at the within-lake spatial scale.

### *Phytoplankton & Periphyton Bioassays*

For the phytoplankton and periphyton bioassays, differences in chlorophyll a concentrations between the four treatments (C, N, P, and N+P) were analysed using the nested ANOVA model of McKone and Lively (1993) to test for significant within-lake differences between chlorophyll a concentrations in response to the various nutrient treatments.

## **Results**

### **Ambient Nutrients**

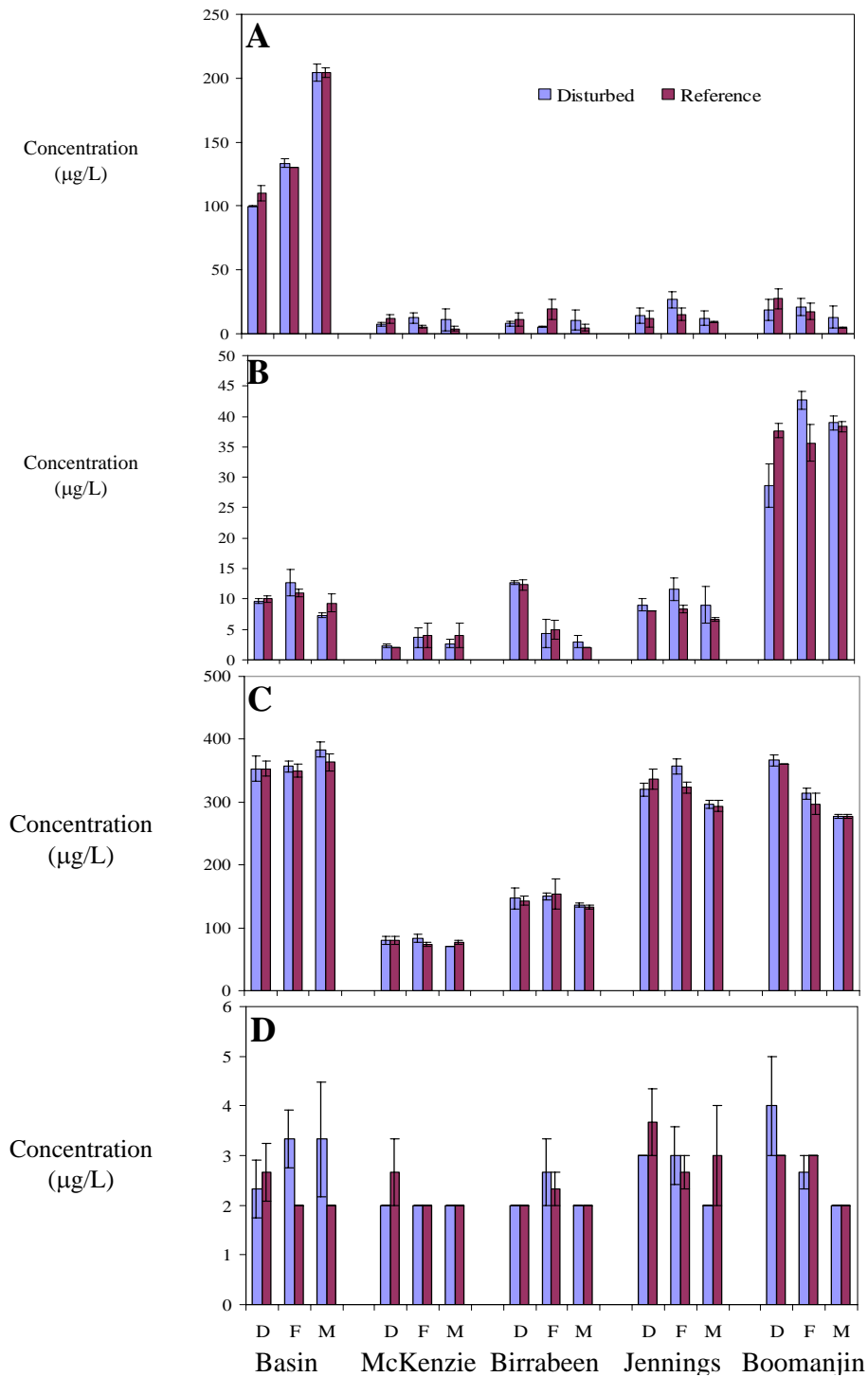
There was very little variation in nutrient concentrations between disturbed and reference sites in the five study lakes (Figure 11). On only one occasion were nutrient concentrations significantly different between disturbed and reference sites in any of the lakes. In that instance, total phosphorus concentrations in the disturbed site of Basin Lake were significantly higher than those in the reference site in the February 2000 sampling period ( $p < 0.01$ ).

Temporal variability in nutrient concentrations was high across the course of the summer (Figure 11). In Basin Lake, ammonium concentrations increased with time to be in excess of 200 µg/L (an order of magnitude greater than the concentrations recorded in all other lakes) in the March 2000 samples (Figure 11a). Lake McKenzie ammonium concentrations were stable over the course of the summer, whilst small declines were observed in Lake Birrabeen, Lake Jennings and Lake Boomanjin (Figure 11a).

Nitrogen oxide concentrations in Lake Boomanjin were up to four times greater than those measured in any of the other lakes sampled, with concentrations in excess of 40 µg/L in some samples (Figure 11b). In Lake Birrabeen, a significant trend of decline in nitrogen oxide concentrations was observed across the course of the summer ( $p < 0.01$ , Figure 11b). Significant differences in temporal concentrations were also found for Basin Lake ( $p = 0.01$ ) and Lake Boomanjin ( $p = 0.03$ ), although these results reflect stochastic temporal fluctuations rather than directional trends over summer (Figure 11b).

Total nitrogen concentrations in the heavily stained perched lakes, Jennings and Boomanjin, were generally higher than those in the clear perched lakes, McKenzie and Birrabeen (Figure 11c). However, the relatively clear Basin Lake had elevated total nitrogen concentrations due to the extremely high ammonium concentrations measured in this system (Figure 11a). There were significant temporal differences in total nitrogen concentrations in Lake Jennings ( $p < 0.01$ ) and Lake Boomanjin ( $p < 0.01$ ), with both lakes having lower concentrations at the end of summer than at the beginning (Figure 11c).

**Figure 11: Mean ( $\pm$  s.e.) ambient nutrient concentrations in disturbed and reference sites in five Fraser Island perched dune lakes in December 1999 (D), February 2000 (F) and March 2000 (M).  
A – Ammonium, B – Nitrogen Oxides, C – Total Nitrogen and D – Total phosphorus**



Total phosphorus concentrations in each lake were always low, highlighting their oligotrophic status (Figure 11d). Temporal variation in total phosphorus concentrations was similarly small, with a significant difference only in Lake Boomanjin ( $p < 0.01$ ) where total phosphorus concentrations fell across the course of the summer (Figure 11d).

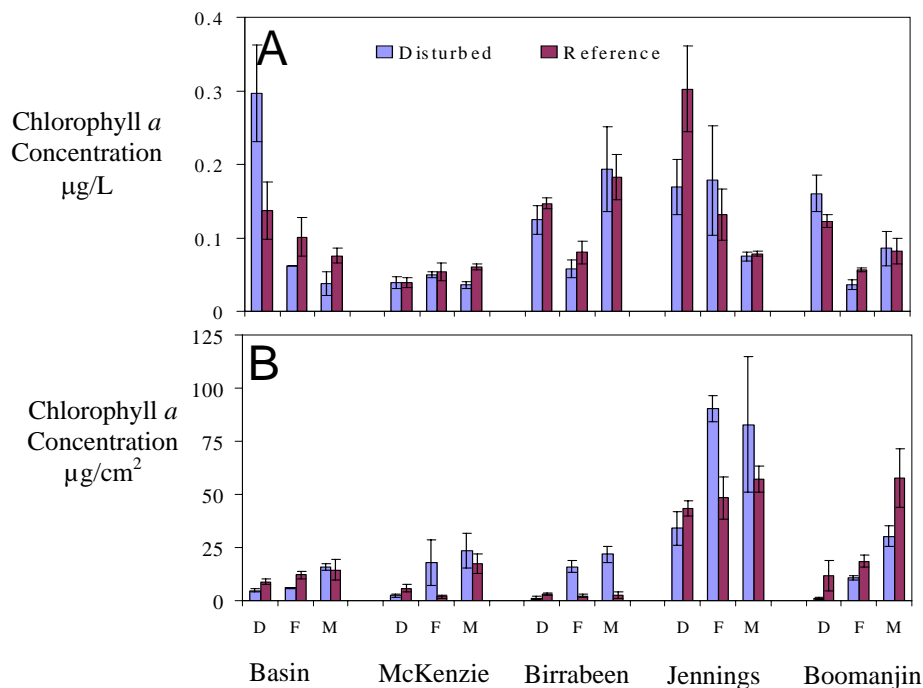
For all five perched dune lakes, the ratio of total nitrogen: total phosphorus concentrations was  $> 20$ , suggesting phosphorus limitation of primary production was likely.

### Phytoplankton Chlorophyll A

Phytoplankton chlorophyll a concentrations were found to be highly variable (Figure 12a) and only one significant difference between disturbed and reference site chlorophyll a concentrations was recorded. In the March 2000 sampling period, higher concentrations were recorded in the reference site than in the disturbed site of Lake McKenzie ( $p=0.02$ ).

In all but Lake McKenzie ( $p=0.11$ ), there was significant temporal variation in phytoplankton chlorophyll a concentrations. In Basin Lake and Lake Jennings, this temporal variability was largely due to a trend of decreasing chlorophyll a concentrations over the summer (Figure 12). In contrast, the significant temporal variation in phytoplankton chlorophyll a concentrations for Lake Birrabreen and Lake Boomanjin were presumably due to mid-summer (February) declines (Figure 12a).

**Figure 12: Mean ( $\pm$  s.e.) chlorophyll a concentrations in disturbed and reference sites in five Fraser Island perched dune lakes in December 1999 (D), February 2000 (F) and March 2000 (M)**



A – Phytoplankton Chlorophyll a, B – Periphyton Chlorophyll a collected from the *Lepironia articulata* reeds within the littoral zone

### Periphyton Chlorophyll A

Across the course of the 1999-2000 summer, significant differences in periphyton chlorophyll a concentrations between disturbed and reference sites were found in all but Lake McKenzie. However, contrary to the prediction that concentrations would be higher in disturbed sites than in reference sites, all significant differences in Basin Lake (December,  $p=0.03$  and February,  $p=0.01$ ) and Lake Boomanjin (February,  $p=0.05$ ) occurred when periphyton chlorophyll a concentrations were higher in reference sites than in disturbed sites. Interestingly, periphyton chlorophyll a concentrations were significantly higher in disturbed sites than in reference sites for Lake Birrabreen (February,  $p<0.01$  and March,  $p=0.01$ ) and Lake Jennings (February,  $p=0.05$ ).

With few exceptions, periphyton chlorophyll a concentrations in all lakes were lowest in the December 1999 samples and highest in the March 2000 samples (Figure 12b). In Basin Lake, Lake Jennings and Lake Boomanjin, this trend of increasing periphyton chlorophyll a concentrations over the course of the summer was consistent across both the disturbed and reference sites (Figure 12b). However, for the clear lakes, McKenzie and Birrabreen, periphyton chlorophyll a concentrations increased in disturbed sites over the course of the summer, whilst remaining relatively low in reference sites (Figure 12b).

### Artificial Reeds – Disturbed Versus Reference Sites

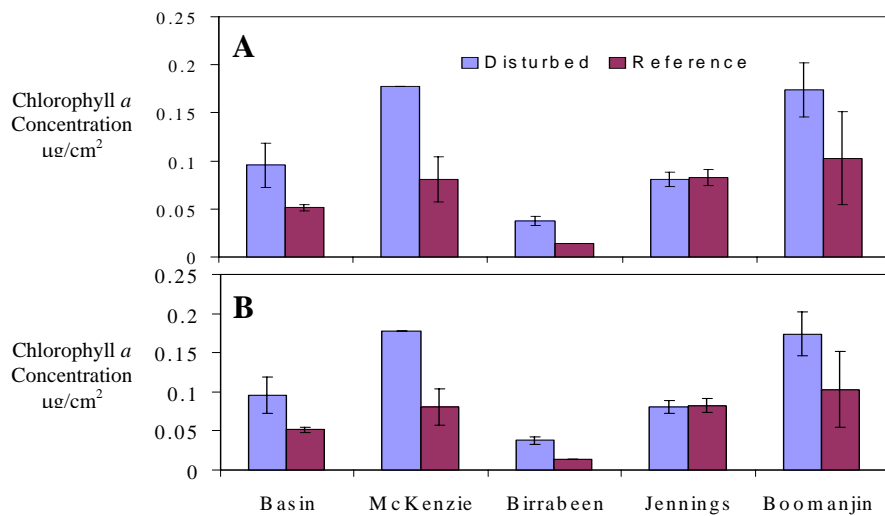
Colonisation of artificial reeds by attached algae was highly variable across lakes (Figure 13a). This variability between lakes was reflected in the significant difference in chlorophyll a concentrations between lakes determined in the ANOVA model (Figure 13a,  $p<0.01$ ). However, chlorophyll a concentrations of attached algae were generally consistent within lakes (Figure 13a), with only concentrations in Lake McKenzie exhibiting

significant differences between disturbed and reference sites ( $p=0.01$ ). As predicted, this difference reflected higher chlorophyll a concentrations on artificial reeds deployed in the disturbed site than on those deployed in the reference site. The artificial reeds in Lake McKenzie were found to be more heavily colonised by algae in the disturbed site than in the reference site (Figure 13a).

### Control Agar Pots – Disturbed Versus Reference Sites

Presumably as a consequence of their visibility to tourists, the retrieval of control pots deployed in disturbed sites was incomplete, particularly in the most popular clear lakes, Lake McKenzie and Lake Birrabeen. These losses inhibited statistically powerful evaluation of chlorophyll a concentrations between reference and disturbed sites. Nevertheless, there was a tendency for periphyton chlorophyll a concentrations to be higher in disturbed sites than in reference sites in Basin Lake, Lake McKenzie, Lake Birrabeen and Lake Boomanjin (Figure 13b). This pattern was not observed in the less frequently visited Lake Jennings, where disturbed and reference site chlorophyll a concentrations were similar (Figure 13b).

**Figure 13: Mean ( $\pm$  s.e.) chlorophyll a concentrations from periphyton growing on artificial substrates in disturbed and reference sites in five perched dune lakes**



A – artificial reeds deployed in December 1999 and retrieved in February 2000, B – control agar pots deployed in November 2000 and retrieved in December 2000 (Basin, Jennings and Boomanjin) or deployed in January 2001 and retrieved in February 2001 (McKenzie and Birrabeen)

### Nutrient Limitation of Phytoplankton

Due to a storm event in November 2000, all of the Lake Boomanjin carboy samples were lost. For the remaining four lakes, there was considerable variability in phytoplankton community responses to nutrient additions (Figure 14a). In Basin Lake, treatment responses differed significantly ( $p=0.01$ ), with higher chlorophyll a concentrations in the P and N+P treatments, relative to C and N treatments (Figure 14a).

In Lake McKenzie, a significant treatment effect ( $p=0.01$ ) was generated by the higher phytoplankton biomass recorded in the N+P treatment relative to that recorded in the C treatment. However, chlorophyll a concentrations in the N treatment were intermediate to those in the C and N+P treatments, suggesting that nitrogen may partially limit phytoplankton production in this system (Figure 14a). Furthermore, since the P treatment did not differ from the C treatment, most of the response in the N+P treatment can presumably be attributed to the added nitrogen rather than the added phosphorus.

Lake Birrabeen chlorophyll a concentrations showed little or no response (relative to C) to the N or P treatments (Figure 14a). However, a significant ( $p<0.01$ ) response in the N+P was observed, suggesting that phytoplankton production may be co-limited by nitrogen and phosphorus in this lake.

The Lake Jennings phytoplankton community exhibited substantial, though not significant, responses to both the N and P treatments (Figure 14a). However, the significant treatment effect ( $p<0.01$ ) was due to the comparatively high chlorophyll a concentrations in the N+P treatment (Figure 14). These results suggest that although separate additions of nitrogen and phosphorus will elicit a response, there is a much greater chlorophyll a response when both nutrients are added simultaneously.

### Nutrient Limitation of Periphyton

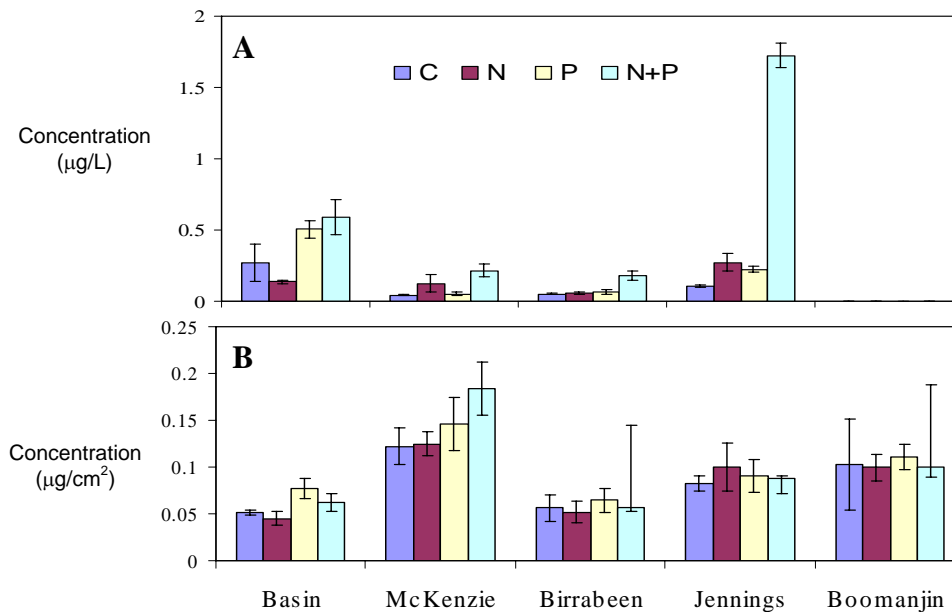
Chlorophyll a concentrations from the periphyton bioassays conducted in November-December 2000 and January-February 2001 were highly variable, both within and between treatments (Figure 14b). There was

considerable variation in the periphyton chlorophyll a responses to the four treatments between the lakes (Figure 14b,  $p < 0.01$ ), but there were no detectable differences between control and nutrient addition treatments in any of the lakes (Figure 14b).

Despite the absence of significant results, there were some trends in chlorophyll a responses to nutrient treatments (Figure 14b). In Basin Lake, chlorophyll a concentrations were highest in the P treatment, which suggests that phosphorus may limit production, as was the case in the phytoplankton bioassays (Figure 14).

In Lake McKenzie, all treatments elicited a substantial algal growth response with uniformly high concentrations of chlorophyll a being recorded (Figure 14b). Periphyton chlorophyll a concentrations in Lake Birrabreen, Lake Jennings and Lake Boomanjin were low and consistent across all treatments, suggesting nutrients may not limit periphyton algal growth in these lakes.

**Figure 14: Mean ( $\pm$  s.e.) chlorophyll a concentrations from algal bioassay nutrient addition treatments in five perched dune lakes**



A – Phytoplankton Bioassays, November 2000, B – Periphyton Bioassays, December 2000 (Basin, Jennings and Boomanjin) or February 2001 (McKenzie and Birrabreen)

## Discussion

On the basis of nutrient and chlorophyll a concentrations, the perched dune lakes examined in this study are oligotrophic (Suttle & Harrison 1988, Dodds & Priscu 1989, Arthington et al. 1990) and as such, nutrient additions are likely to lead to increased algal biomass (Neill 1988, Shortreed & Stockner 1990, Hawes & Smith 1993). Furthermore, the absence of differences in nutrient concentrations between disturbed and reference sites over the course of the 1999-2000 summer does not necessarily mean that tourists are not adding nutrients to these oligotrophic systems (Butler et al. 1996). In fact, it is likely that the absence of increases in ambient nutrient concentrations is due to rapid assimilation of nutrients by algae (Axler & Reuter 1996, Havens et al. 1996b, Cottingham et al. 1997). As a result, monitoring for changes in ambient nutrient concentrations in these systems may be misleading, since rapid biological uptake is likely to occur before changes in nutrient concentrations can be reliably detected (Arthington et al. 1989, Outridge et al. 1989). As a result, bioindicators are likely to provide the best indications of system responses to nutrient inputs in these oligotrophic lakes (Barnese & Schelske 1994, Havens et al. 1996b, McCormick, Rawlik, Lurding, Smith & Sklar 1996, McCormick & Stevenson 1998).

The results from the algal bioassays further support the assumption that nutrient additions are likely to stimulate rapid algal growth in these lakes. All lakes showed significant responses to at least one (N, P or N+P) of the nutrient addition treatments in the phytoplankton bioassays. However, the responses of phytoplankton communities to nutrient additions were lake-specific. This is particularly interesting given that the most northern and southern lakes were separated by a distance of less than 30 kms (see Figure 6) and such differential algal responses to nutrient additions are rarely reported for lakes within the same region (White 1983, Elser, Marzolf & Goldman 1990). Furthermore, since the catchment characteristics of these lakes are almost identical (Sinclair 2000, UNESCO 2001), there is no clear *a priori* reason for anticipating this degree of lake-specific algal

response to nutrient additions. However, since these systems are perched above the regional aquifer and consequently represent discrete hydrological units (Bayly 1964, James 1984, Timms 1986), it may be that these differences in algal responses to nutrient additions are the result of differences in species composition and food web dynamics (Agrawal 1998, Aoki & Mizushima 2001).

Although the nutrient concentrations used in the algal bioassays were substantially higher than ambient nutrient concentrations (see Table 8), they still only represented modest levels of nutrient additions relative to those likely to come from tourist sources (Strasinger 1994). As such, the lack of significant growth responses recorded for periphyton in the experimental bioassays does not necessarily reflect the likely consequences of ongoing nutrient additions from tourist sources. Despite the absence of statistically significant responses to nutrient additions, there were some trends towards differential growth responses among periphyton communities in Basin Lake and Lake McKenzie.

For example, the P treatment elicited a strong algal growth response in Basin Lake and periphyton chlorophyll a responses tended to be greater in the N+P treatment in Lake McKenzie. Contrastingly, the periphyton communities in Lake Jennings, Lake Boomanjin and Lake Birrabeen did not follow the patterns observed in phytoplankton bioassays. The absence of significant responses in these three lakes suggests that other variables may be responsible for the regulation and control of periphyton algal biomass (Rhee & Gotham 1980, Jones, Young, Hartley & Bailey-Watts 1996, Petersen, Chen & Kemp 1997, Havens, Philips, Cichra & Li 1998). Since grazer abundance has been found to be considerably higher in Lake Birrabeen than in any of the other lakes studied here (Hadwen unpublished data), the absence of nutrient-initiated chlorophyll a responses in this lake may reflect a comparatively high and simultaneous regulation of chlorophyll a concentrations through top-down grazer control (Hunter 1980, Mazumder, Taylor, McQueen & Lean 1989, France, Howell, Paterson & Welbourn 1991, Gresens 1995).

The treatment-independent and comparatively low periphyton chlorophyll a concentrations for Lake Jennings and Lake Boomanjin suggest that light may play an important role in regulating periphyton production in these lakes (Marks & Lowe 1993, van Dijk 1993, Bourassa & Cattaneo 2000). Since tannins stain both of these systems, light attenuation through the water column may inhibit periphyton production (Effler et al. 1985, van Dijk 1993, Bukaveckas & Robbins-Forbes 2000). If this is the case, nutrient additions may have no significant effects on periphyton chlorophyll a concentrations (Rhee & Gotham 1980, Effler et al. 1985, Jones et al. 1996, Schwarz, Hawes & Howard-Williams 1996). In contrast, the higher (across all treatments) periphyton biomass in the clear Lake McKenzie suggests that light availability does not limit periphyton production in this system. In fact, the results from monitoring, artificial reed and agar pot experiments suggest that periphyton grows in Lake McKenzie wherever a surface is available for colonisation. Periphyton biomass may, therefore, be substrate limited in Lake McKenzie (as in other systems - Cattaneo & Amireault 1992, Goldsborough 1994, Smoot *et al.* 1998), particularly in the disturbed site where reed density is much lower as a consequence of exposure to the prevailing south-easterly winds and trampling by tourists.

In Lake McKenzie and Lake Birrabeen, collections from *Lepironia articulata* stems, artificial reeds and agar pots indicate that periphyton production (and biomass accrual) differs in disturbed and reference sites. With the susceptibility of these systems to deleterious impacts from tourist activities already recognised in earlier sections of this document, it is reasonable to suggest that nutrient inputs from tourists may be, in part, fuelling these patterns. If this is the case, then deleterious ecological outcomes may result if the current levels of tourist use of these dune lakes continue unabated (Hansson 1988, 1992). At the very least, excessive attached algal growth may be unsightly and have adverse effects on the perceptions and motivations of tourists visiting these systems (Buckley & Pannell 1990). If this is the case then increases in algal biomass are likely to influence the sustainability of tourism on Fraser Island, particularly given the value of these systems as swimming and recreation areas (Butler et al. 1996).

## *Chapter 6*

### **Discussion**

#### **Can Tourists Pose a Threat to the Nutrient Status of Oligotrophic Waterbodies?**

Excessive nutrient additions to oligotrophic freshwater systems threaten their long-term preservation and sustainable use as sites for recreation (Leung & Marion 2000, Newsome et al. 2002). Whilst large quantities of nutrients often lead to highly dramatic and visible consequences (Havens et al. 1996a, Havens et al. 2001, Anon 2002a), the scale at which tourists add nutrients to oligotrophic systems requires considerable understanding of the processes that maintain these systems and how these might affect the outcomes of nutrient additions (Butler et al. 1996).

Whilst they have been largely ignored in the literature, tourists can represent a substantial source of nutrient inputs into oligotrophic waterbodies (Butler et al. 1996). Many contemporary texts have highlighted the importance of waterbodies as focal sites for recreation and hinted at potential effects of tourism on water quality (Lueng & Marion 2000, Weaver 2001, Page & Dowling 2002, Newsome et al. 2002), yet very few studies have aimed at developing our understanding of tourist impacts on oligotrophic aquatic systems. This study has identified the risk of nutrient additions from tourist sources and provided evidence to suggest that the ecological consequences of ongoing nutrient additions are likely to be significant. Whilst the sources and quantity of nutrients entering dune lakes on Fraser Island are difficult to determine, there is little doubt that many of these systems represent significant recreation sites for tourists on the island. The tourist surveys conducted at Lake McKenzie highlight the appeal of these lakes as swimming spots. Interestingly, tourists surveyed appeared to display generally broad knowledge on the consequences of their visits (personal observation). Since many respondents expressed concern over any moves towards increasingly built facilities to accommodate increasing visitor numbers, it is likely to be important, from a management perspective, that the natural values that attract tourists to Fraser Island are not lost (Anon 1995, Gosselin 1997, Park 1999).

Given the appeal of perched dune lakes on Fraser Island to tourists established in the first phase of this research, the important next step in determining the potential impacts of tourists should be the identification of how much pressure the system is likely to be under from current levels of tourist use (Newsome et al. 2002). The Tourist Pressure Index (TPI) was developed in order to quantify tourist pressure on Fraser Island dune lakes, by integrating logistical, social and bio-physical information to predict the appeal of the system to tourists. The success of this index is highlighted by the fact that it positively identified known tourist hot spots on Fraser Island as those areas that are most likely to be threatened by excessive tourist use (Sinclair 2000). Furthermore, the real strength of the index comes when TPI scores are cross-referenced with limnological data. By comparing the systems determined to be most heavily visited by tourists (TPI) with those that appear to be most susceptible to adverse changes (limnological data), it was evident that Lake McKenzie required considerable attention both in terms of scientific investigations (monitoring) and management plans (tourist facilities). This approach to the assessment of natural area management priorities, which couples environmental data with sociological and logistical information, promises to be a useful technique that may be applicable to aquatic and terrestrial sites in the future.

One of the most substantial findings from calculations of TPI for the lakes on Fraser Island is the fact that the range of pressure from tourists differs greatly from lake to lake. In turn, it is likely that the nutrient loadings (from human sources) to lakes will also differ markedly, despite the fact that they might be relatively similar in terms of their limnological characteristics (Bayly 1964, Timms 1982, Arthington et al. 1986, Timms 1986a). As such, management and monitoring priorities should focus on the systems identified as being most at risk from excessive tourist use (i.e. those with high TPI scores).

#### **Detecting Impacts of Low-Level Nutrient Inputs**

Increasingly, the use of ambient nutrient concentrations in monitoring programs in oligotrophic systems is being questioned (Kelly & Whitton 1998, McCormick & Stevenson 1998, Schallenberg & Burns 1999, Burns & Ryder 2001). One of the main limitations of monitoring ambient nutrient concentrations in oligotrophic systems is the short residence times of nutrients in the water column of these systems, by virtue of high uptake rates of primary producers (Dodds 1995, Axler & Reuter 1996, Budy et al. 1998). As such, it is likely that significant changes in ambient nutrient concentrations will only be detected after substantial changes in primary production and community structure have already occurred (Cairns, McCormick & Niederlehner 1993, Whitton & Kelly 1995, Havens et al. 1996a, Havens et al. 2001). In these instances, measurement of changes in ambient nutrient concentrations may be of limited value in monitoring programs, since many of the biological and chemical changes that typify eutrophication are irreversible (Larson 1996, Guoxiang & Peimen 1999, Anon 2002a). The results presented in this study add further support to the suggestion that the measurement of ambient nutrient



concentrations (if conducted in isolation of measurement of other factors) in monitoring programs may yield unrealistic and misleading results. For example, the comparisons between data from Arthington et al. (1990) and the present study showed that phytoplankton chlorophyll *a* concentrations had risen in all five lakes, whilst ambient nutrient concentrations had only risen in the window lakes. The higher trophic status of the window lakes suggests that the use of ambient nutrient concentrations in monitoring is likely to only be able to adequately detect the consequences of elevated nutrient loadings well after they have occurred (Underwood & Kennelly 1990, Lake 2002).

As suggested by numerous researchers (Loeb et al. 1983, Hansson 1990, Axler & Reuter 1996, Vis et al. 1998), phytoplankton chlorophyll *a* concentrations were found to be not particularly useful for identifying the local impacts of tourists in oligotrophic systems. Despite the fact that phytoplankton communities exhibited measurable growth responses in nutrient algal bioassays (as determined from algal bioassays), the natural variability and stochasticity of phytoplankton communities in large oligotrophic lakes inhibit their utility as reliable indicators of change (Loeb et al. 1983, McCormick & Stevenson 1998). Nevertheless, phytoplankton chlorophyll *a* concentrations may be useful indicators of long-term changes - like those observed between February 1990 (Arthington et al. 1990) and February 1999 - in oligotrophic systems. However, as discussed in the introductory section of this document, detection of changes over long periods of time are unlikely to be able to assist in the development of sustainable management plans for the lakes on Fraser Island (Underwood & Kennelly 1990).

Whilst the utility of phytoplankton as an indicator of environmental responses to nutrient additions is somewhat restricted, there is substantial evidence to suggest that periphyton communities may enable more spatially and temporally appropriate assessments of tourist impacts in perched dune lakes (Loeb et al. 1983, Matilla & Raisanen 1998, McCormick & Stevenson 1998, Vis et al. 1998). In the current study, periphyton biomass (measured as chlorophyll *a* concentrations) was found to be significantly higher in disturbed or accessible sites than in reference sites in the clear perched dune lakes (McKenzie and Birrabeen). This result suggests that the activities of tourists, in conjunction with the high light and substrate availability in clear lakes, promote periphyton growth. Whilst the effects of tannins on light penetration may dampen the effects of tourists by limiting periphyton production (Marks & Lowe 1993, van Dijk 1993, Bourassa & Cattaneo 2000), there is also some evidence to suggest that periphyton growth may also be enhanced by nutrient additions in some of the stained systems on Fraser Island (see algal bioassay results).

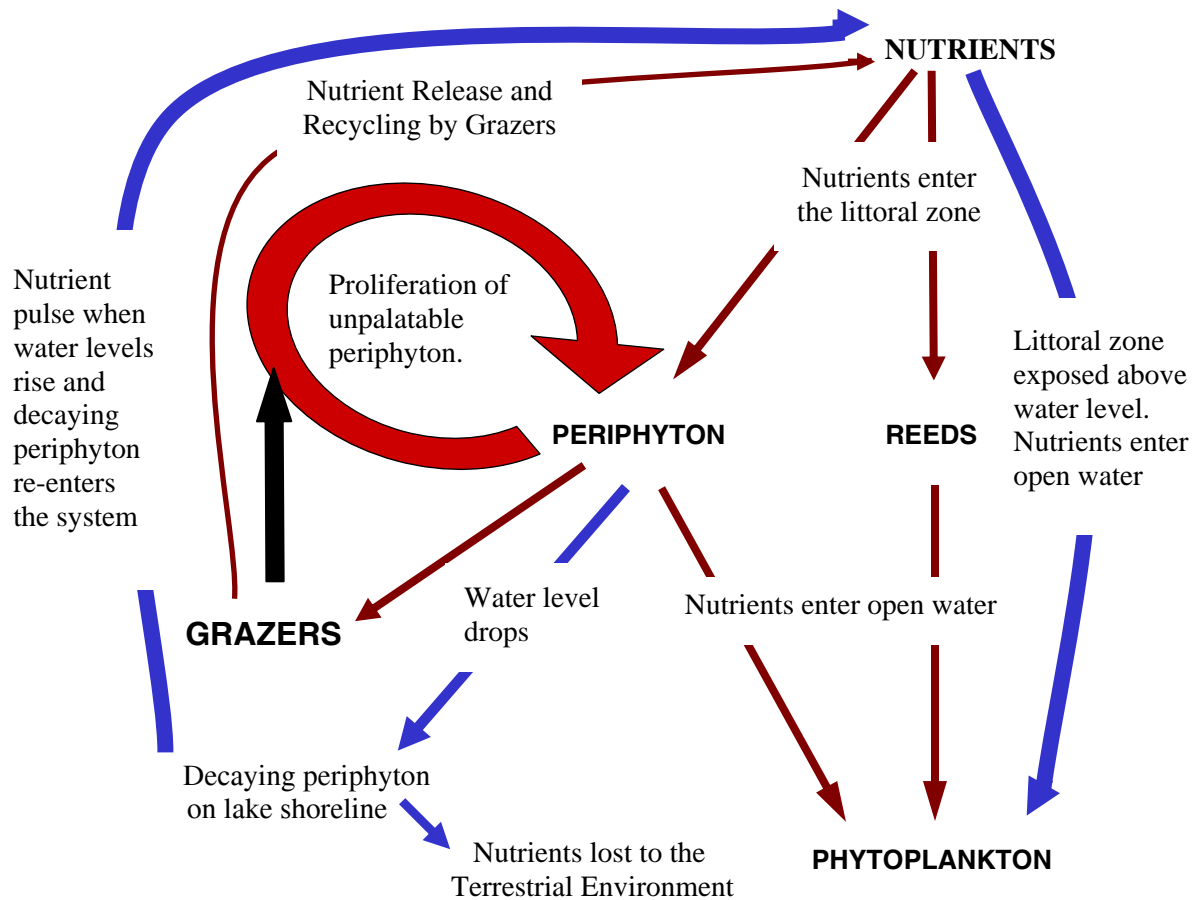
The long-term fate of nutrient additions in the littoral zone of Fraser Island dune lakes is likely to be determined by the structure and functioning of food webs in the system concerned (Hansson 1992, Mazumder & Lean 1994, Pace & Cole 1996, Raffaelli 1999). If increased periphyton productivity and biomass accrual translate into increased secondary production through a grazing pathway, then ongoing additions may have no long-term deleterious consequences in these lakes (Dodds 1991, France et al. 1991, Agrawal 1998). However, ongoing nutrient additions from tourist sources may stimulate periphyton growth beyond the regulatory capacity of consumers (Carpenter et al. 1987, Hunter & Price 1992, Mazumder & Lean 1994). Furthermore, nutrient additions may ultimately favour the proliferation of unpalatable algal species and/or macrophytes (Ganf & Oliver 1982, Smith 1986).

Since perched dune lakes are hydrologically closed (Bayly 1964, Timms 1982, James 1984, Arthington et al. 1986, Arthington et al. 1990), considerable water level fluctuations may influence the interplay between tourist nutrient additions (and periphyton growth) and the regulatory capacity of grazers (Figure 15). For instance, although ongoing nutrient additions are likely to stimulate periphyton productivity and biomass accrual, water level fluctuations will influence both the availability of substrate and the quantity of wetted periphyton (Figure 15). If water levels drop dramatically, large quantities of periphyton will desiccate and fall off the *Lepironia articulata* stems. This desiccated periphyton may either fall back into the lake where it will be a source of nutrients for periphyton or macrophytes, or it will lie on the shoreline and re-enter the system as a pulse of nutrients when water levels rise again. In the latter case, these inputs may lead to phytoplankton blooms, since periphyton communities will be less able to assimilate these nutrients rapidly, courtesy of their newfound depth in the water column and the subsequent effects of light attenuation (Effler, Schafran & Driscoll 1985, Bukaveckas & Robbins-Forbes 2000, Cleuvers & Ratte 2002). If this is the case, the consequences of nutrient additions in perched dune lakes may be most pronounced only when water levels are stable over an extended period of time, when conditions can promote the proliferation of periphyton biomass and/or the dominance of unpalatable algal communities (Welch et al. 1988, Fong et al. 1993, Scheffer, Rinaldi, Gragnani, Mur & van Nes 1997).

From a tourist use perspective, increasing periphyton biomass in response to tourist activities in the accessible areas of the clear perched dune lakes on Fraser Island may detract considerably from the recreational appeal of these systems (King & Mace 1974, Liddle & Scorgie 1980, Welch et al. 1988, Butler et al. 1996). As such, the accrual of periphyton biomass in areas of lakes frequented by tourists may be both ecologically and sociologically undesirable. Furthermore, whilst changes in biomass can indicate substantial changes in nutrient resources in these oligotrophic systems, an obvious next step for this research is to investigate the species composition of periphyton and phytoplankton communities in disturbed and reference sites of heavily visited

lakes. Such an approach would aim to quantify algal compositional changes following nutrient inputs and sediment re-suspension from tourists (King & Mace 1974, Liddle & Scorgie 1980).

**Figure 15: Conceptual model of nutrient dynamics in perched dune lakes on Fraser Island, with particular emphasis on the effects of water level fluctuations and grazers**



## Management Implications and Recommendations

### Ongoing Assessment of the Tourist Threat to Perched Dune Lakes

On the basis of their appeal to tourists, high TPI scores and oligotrophic conditions, the clear perched dune lakes on Fraser Island (Lake McKenzie and Lake Birrabeen) require the most resources for sustainable management and monitoring purposes. For Lake McKenzie in particular, extremely high visitation levels over the course of summer are ultimately likely to influence the ecology of the system, particularly if a considerable proportion of visitors add nutrients to the lake, either through urination, washing or bathing activities (Strasinger 1994, Butler et al. 1996). As particular areas of Fraser Island are currently undergoing planning and development to cater for increases in visitation levels (personal observation), periodic recalculation of TPI scores promises to adjust the assessment of tourism pressure accordingly. Furthermore, the TPI model could also be applied to some of the non-lake tourist attractions on Fraser Island such as Eli Creek, Central Station, Eurong and The Cathedrals (Figure 2), to provide useful information to resource managers in light of expected increases in visitation levels to all of these sites (Sinclair 2000, Anon 1998, 2002c).

In addition, the tourist survey conducted at Lake McKenzie (Appendix A) should probably be adopted (and revised if necessary) for ongoing monitoring purposes. The implementation of regular surveying would generate an invaluable database of the demographics of people that visit Fraser Island, and would also be useful for mapping temporal changes (should they occur) in people's perceptions of these systems (Beeho & Prentice 1997, Chin, More, Wallington & Dowling 2000, Puczko & Ratz 2000). Ideally, it would be useful to conduct surveys at numerous other perched dune lakes (and other tourist destinations) on the island, to determine whether or not the perceptions of tourists are influenced by the sites that they visit. Furthermore, quantitative data on tourist

visitation levels at numerous lakes on Fraser Island promises to facilitate the calculation of tourist loads (for nitrogen and phosphorus) as well as from other sources. These calculations will enable the prediction of the relative contribution of tourists to lake-wide nutrient loads, thereby providing an indication of the likely impacts of tourists on a lake-by-lake basis.

### **Adoption of a Biomonitoring Program**

As discussed in the introduction of this document, the temporal and spatial scales at which monitoring is conducted will depend on the monitoring goals (Underwood & Kennelly 1990, Lake 2002). In turn, the particular components of the system to be monitored will influence the results, since they may reflect changes at drastically different scales. For example, whilst the current monitoring strategy for dune lakes on Fraser Island, which is based on quarterly measurements of ambient nutrient and phytoplankton chlorophyll *a* concentrations in the middle of lakes (Hockings 1999), is unlikely to be able to detect environmental responses to tourist activities, particularly nutrient additions, in the perched dune lakes on Fraser Island, these measures have already been shown to be useful in detecting long-term changes in the trophic status of these systems (based on comparisons between data from Arthington et al. 1990 and the current study). However, it should be noted that the detection of impacts at such a temporal scale is unlikely to provide useful information for resource managers, particularly since many of the changes detected will be irreversible (Larson 1996, Guoxiang & Peimen 1999).

Given that monitoring programs typically aim to detect changes before they become irreversible problems (McCormick & Stevenson 1998, Schallenberg & Burns 2001), the adoption of a more spatio-temporally explicit monitoring program would best suit the needs of resource managers on Fraser Island (Underwood 1996). On the basis of the findings of this study, the measurement of periphyton biomass (chlorophyll *a* concentrations) in disturbed and reference sites in heavily visited lakes promises to be a cheap and efficient indicator of tourist-mediated changes in littoral zone production (see monitoring and artificial reed results). Importantly, it is crucial that the appropriate scale and sampling design issues are addressed to ensure adequate sampling breadth (Underwood & Kennelly 1990). In other words, cost-cutting should not inhibit the capacity of the monitoring program to adequately detect environmental changes (Underwood & Kennelly 1990, Underwood 1996). Furthermore, since the collection and analysis of water samples for ambient nutrient concentrations is both expensive and potentially misleading at the scale at which current monitoring is conducted (Underwood & Kennelly 1990), the monitoring of periphyton biomass could replace this component of the current regime if funding support for monitoring is limited (Vinebrooke & Graham 1997, McCormick & Stevenson 1998, Vis et al. 1998).

There are obvious signs, in numerous ecosystems on Fraser Island, that increasing tourist numbers threaten the sustainable use of this region for tourism purposes (Sinclair 2000). This study adds weight to the concerns of resource managers on Fraser Island that unregulated tourist activities may lead to undesirable shifts in the trophic status of dune lake systems on the island (Sinclair 2000). As they stand, many of the issues raised in this thesis deserve considerable further attention, both scientifically and for management purposes.

There is little doubt that unrestricted and ongoing tourist use of the perched dune lakes on Fraser Island threatens their long-term sustainability and conservation (Sinclair 2000) and scientifically sound management strategies are likely to be needed to ensure that anthropogenic nutrient additions to these systems are minimised. Unfortunately, the task of implementing a scientifically rigorous monitoring and management strategy is not likely to be easy, particularly given the tight association between funding and visitation levels in this region (Sinclair 2000, Anon 2002c). Nevertheless, exploitation of Fraser Island for short-term tourism industry gains will threaten the long-term conservation values of this World Heritage Area. However, neglectful management will threaten the long-term sustainability of tourism on the island (Park 1999). In view of the threats that tourism poses to the long-term health of dune lakes on Fraser Island, achievement of the conservation mandate of the Fraser Island World Heritage Area Management Committee is most likely going to have to involve tighter visitor restrictions in the future, to either limit the number of tourists in the region or, at the very least, to limit their impacts on the environment (Leung & Marion 2000, Newsome et al. 2002, Page & Dowling 2002, Weaver 2002).

## **Appendix A: Tourist Survey**

*This survey is part of a PhD Project investigating the potential impacts of tourists on the perched dune lakes of Fraser Island. The study is being conducted through the Centre for Catchment and In-Stream Research (CCISR) at Griffith University, with funding from the Cooperative Research Centre for Sustainable Tourism.*

1. How many times have you been to Fraser Island? Please tick ONE answer only.
  - This is my first time
  - 2 – 4 previous visits
  - 5 –10 previous visits
  - > 10 previous visits
  
2. How long do you intend to stay on Fraser Island on this trip? Please tick ONE answer only.
  - Brief Excursion (< 5 hours)
  - Day Excursion (1 day)
  - Overnight Stay (2 days/1 night)
  - Short Break (3 – 6 days)
  - Holiday (1 week – 4 weeks)
  - Extended Holiday (> 4 weeks)
  - Other (Please specify type and length of stay) \_\_\_\_\_
  
3. What type of accommodation do you normally use when staying on Fraser Island overnight? Please tick ONE answer only.
  - Camping in undeveloped campsite
  - Camping in designated campsite
  - Resort / Hotel
  - House
  - Other (please specify) \_\_\_\_\_
  
4. How many people, including yourself, are you here with today?  
Adults \_\_\_\_\_  
Children (under 18 years old) \_\_\_\_\_
  
5. What type of group are you here with today? Tick ONE best description.
  - Alone
  - Couple
  - Family
  - Friends
  - Tour Group
  - Organised Group (club or society)
  - Other (please specify) \_\_\_\_\_
  
6. Before arriving on Fraser Island, did you plan to visit this particular lake?  
 Yes                       No

7. How many times have you visited this lake on your current visit to Fraser Island?
- This is the first time
  - 4 times
  - 5 – 9 times
  - More than 10 times
8. Which recreational activities do you intend to participate in whilst at this particular lake? (Tick one or more).
- Sport (eg. football, frisbee)
  - Picnicking
  - Bushwalking
  - Sightseeing / Photography
  - Canoeing / Kayaking
  - Swimming
  - Sunbathing
  - Relaxing / Reading
  - Other (please specify) \_\_\_\_\_
9. Have you swum in this lake today? If no, proceed to question 16, if yes continue on to question 10.
- Yes                       No
10. Approximately how long did you spend in the water (in this lake) today? Please tick ONE box only.
- 0 – 10 minutes
  - 11 – 20 minutes
  - 21 – 30 minutes
  - 31 – 40 minutes
  - 41 – 50 minutes
  - 51 – 60 minutes
  - 1 hour
11. Please rate the following factors in terms of their importance in your decision to swim at this site. Circle your choice on the scale (1 = not at all important, 5 = very important).
- |                             |   |   |   |   |   |
|-----------------------------|---|---|---|---|---|
| Clearness, purity of water  | 1 | 2 | 3 | 4 | 5 |
| Water temperature           | 1 | 2 | 3 | 4 | 5 |
| Accessibility               | 1 | 2 | 3 | 4 | 5 |
| Being in a natural setting  | 1 | 2 | 3 | 4 | 5 |
| Facilities provided at site | 1 | 2 | 3 | 4 | 5 |
| Number of people present    | 1 | 2 | 3 | 4 | 5 |
12. How do you feel about the number of people at this site today? Tick ONE best description.
- Far too few
  - Too few
  - About right
  - Too many
  - Far too many

13. How do you feel about the quality of water at this site today? Tick ONE best description.

- Very Poor
- Poor
- Fair
- Good
- Excellent

14. To what extent did the quality of the water at this site effect the enjoyment and/or satisfaction of your swim? Tick ONE of the following.

- Detracted greatly
- Detracted slightly
- No effect
- Added slightly
- Added greatly

15. If you were DISSATISFIED with the quality of the water at this site, please indicate reasons why you felt this way by placing a tick in the appropriate box(es).

- Water clarity/visibility
- Water colour
- Water odour
- Surface litter/debris
- Algal growth on reeds
- Wave action
- Other (please specify) \_\_\_\_\_

16. What do you think of the facilities provided at this site?

- Very Poor
- Poor
- Fair
- Good
- Excellent

17. What other lakes have you visited during your stay on the island?

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18. Have you swum in any of the other lakes on the island? If yes, which one(s).

- No
- Yes

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19. Where would you prefer to swim? Please tick ONE answer only.

- A clear lake
- A brown lake
- A stream
- The ocean
- A swimming pool

20. Gender (please tick)

- Male             Female

21. In what age group do you fall?

- 18 years or under
- 19 - 24 years
- 25 - 34 years
- 35 - 44 years
- 45 - 54 years
- 55 years or over

22. What is your usual place of residence?

Australian Location (postcode) \_\_\_\_\_

**or**

Other Country (please specify) \_\_\_\_\_

23. Any other comments:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

*Thank you very much for taking the time to complete this survey.*

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## **Glossary**

<b>Algal Bioassays</b>	experiments conducted to assess the response of algae to nutrient additions
<b>Ambient nutrient concentrations</b>	standing concentrations of nutrients
<b>Artificial Substrates</b>	inert substrates deployed in aquatic systems to assess periphyton accumulation.
<b>Chlorophyll a</b>	the photosynthetic component of algal cells. Often used as an indicator of algal biomass, since chlorophyll a concentrations are positively correlated with algal biomass.
<b>Epilimnion</b>	upper layer of water column
<b>Eutrophication</b>	nutrient pollution, or the process of increasing the trophic status of an aquatic system.
<b>Littoral Zone</b>	the area comprising the shoreline reaches of a lake or stream
<b>Phytoplankton</b>	free-floating (usually single celled) algae.
<b>Periphyton</b>	attached algae. Grows on surfaces.
<b>Trophic Status</b>	a measure of the productivity of a system, usually based on nutrient concentrations. Unproductive systems are referred to as being oligotrophic. Reasonably productive systems are mesotrophic and highly productive systems are eutrophic.



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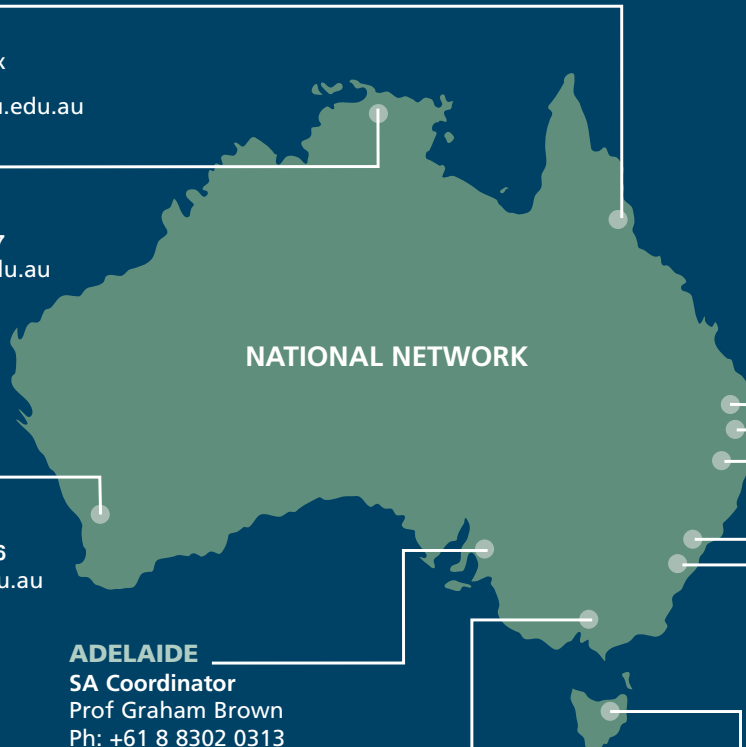
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