Algal beds and threatened aquatic fauna in Great Lake: Current status, responses to lake level and management recommendations

October 2001

Peter E Davies Freshwater Systems

Report to Hydro Tasmania and Threatened Species Unit, DPIWE

1. Introduction

Major changes in the flora and fauna of Great Lake have occurred since management of levels for hydro power generation commenced in the 1920's. Early records of Great Lake (e.g. Legge and Cramp, in Banks 1973) indicated that the lake had extensive areas of emergent and submerged macrophytes associated with shallow, shelving shorelines. These macrophyte communities were associated with several waterbird species infrequently or no longer observed at the Lake. Davies and Sloane (1988) described the major changes in characteristics of brown trout populations in the lake since the 1920's, noting a major 'boom' period in the fish population during the 10 – 20 years following construction of the Miena Dam. They attributed increases in fish growth rates and size to increases in access to freshly inundated shorelines, with associated increases in food availability. The period from the 1940's to the present was characterised by much lower and relatively stable growth rates of trout. During this period, the lake shore has been dominated by a characteristic 'bath-tub ring' (hereafter BTR) consisting of periodically inundated and exposed boulder-cobble armoured substrate. The BTR zone is also typified by absence of finer sediment grain sizes, largely due to the relatively high wave energies during periods of inundation, and an absence of terrestrial or aquatic vegetation.

A series of extensive algal beds, generally known as the 'shrimp beds', were known to exist in Great Lake at least since the 1960's, and probably earlier. Fulton (1983) first described the presence of limited areas of lake bed dominated by *Chara* or *Nitella* ‘stonewort’ algae during surveys conducted in the late 1970’s. He also ascertained that the majority of the lake bed (> 80%), below ca 1020 m altitude, is characterised by soft fine-grained sediment deposits with no associated algal or plant communities, whose fauna is dominated by worms (oligochaetes) and chironomids (midges). His study was focussed on comparing soft sediment faunas of Great and Arthurs Lakes, and his sampling method (Eckman grabs) did not allow sampling of the fauna associated with the BTR zone or algal beds – both of which are dominated by a cobble-boulder armour layer.

Subsequent investigations were conducted in the late 1980’s (Davies and Fulton 1987) including exploratory dive surveys of algal distribution. This work showed that:

- There were five large and three smaller algal beds within the lake;
- All algal beds were clearly delimited in depth range, at both the upper and lower margins;
- That they only occurred on shorelines sheltered from strong pre-frontal north-westerly and westerly winds;
- That they were associated with deposits of fine sediment on the upper slopes of the lake bed profile;
- That, in 1987, they were constrained between approximately 1024 and 1020.6 m altitude, with the lower margin being consistent across all beds surveyed and associated with the upper edge of the original (pre-dam) lake shore. The similarity in the altitude of the lower margin of all beds surveyed suggested a limit imposed by light attenuation.

All beds were dominated by *Chara* and *Nitella* algae, with several other macrophyte species occurring only in parts of Todds Corner. Herefater in this report, these beds are referred to as *Chara* beds only.

Exploratory, qualitative sampling suggested that a distinct faunal community was associated with these beds (Davies and Fulton unpub. data), as opposed to the community characterising the majority of the lake bed (Fulton 1983). That fauna appeared to be characterised by the presence of the endemic crustacean (‘Great Lake shrimp') *Paranaspides lacustris*, and larger numbers of the endemic fish *Paragalaxias eleotroides*. The endangered endemic limpet *Ancylastrum cumingianus* was also observed there, whereas it was apparently absent from the BTR zone and deep lake sediments.

In addition, a netting survey of a range of habitats within the lake (Davies and Fulton 1987) showed that:

- juvenile and old (>6 years) brown trout, the latter frequently in poor condition, generally inhabited the BTR zone;
- a predominance of rainbow trout and of poor-conditioned older brown trout were caught in nets suspended in open water at the surface;
- brown trout, frequently in good condition, ranging between 2 and 6 years of age formed the majority of the catch recorded from nets set on the lake bed within the *Chara* beds, and that the age and size characteristics of this sub-population were consistent with those fish observed in the lake's principal spawning run at Liawenee Canal (Davies and Sloane 1987);
- stomach contents of trout caught in nets set within the *Chara* beds were dominated by *Paranaspides* and *Paragalaxias* and caddis nymphs. A proportion of stomachs from trout caught in the BTR zone and open water also contained *Paranaspides* – indicating that these fish had also fed in the *Chara* beds.

Davies and Sloane (1988) described a negative correlation between trout condition in anglers catches and lake depth. They interpreted this as being due to the greater proportion of good-condition trout in anglers catches as lake levels decreased, as the proportion of fishing effort in the vicinity of the *Chara* beds increased. This argument was predicated on an assumption that brown trout frequently have localised home-ranges on lake beds, as has been observed elsewhere.

Overall, this early work led to the following initial conclusions, that:

- the *Chara* beds were a major reservoir of aquatic faunal and floral biodiversity, particularly in their role as vestigial habitat for fauna endemic to the lake;

- the occurrence of significant areas of *Chara* in the absence of other macrophyte species was a characteristic of a regulated lake with significant short- and long-term changes in level, as observed elsewhere;
- the beds were significant feeding habitats for brown trout, especially that portion of the population responsible for the majority of spawning and hence recruitment;
- the trout population did not feed significantly on the benthic fauna of the dominant substrate of the lake, deep water fine silt sediments, which therefore did not contribute directly to fishery productivity;
- as a result, the beds may be a major driver of fishery production within the lake and hence their management should be seen as central to maintaining the viability of the Great Lake trout fishery;
- in addition, the beds are probably the major habitat for a number of the aquatic species endemic to this lake, and listed under the Threatened Species Protection Act (1995);
- the location of the beds suggests that they are highly vulnerable to wave action, and dependent on sites with low wave energy and the potential for fine silt deposition at positions high enough on the shore profile for light not to limit growth.
- periodic observations since the 1960's have been made of exposure ('dewatering') of the upper areas of the beds, with associated die-off.

The above conclusion regarding importance of the beds as habitat for endemic and threatened fauna in the lake is not supported by rigorous sampling. Davies (1999) recommended that this be rectified by a stratified sampling program which formally evaluates abundance and diversity of macroinvertebrate and fish within and outside the algal beds, and determines the true status of these species and the degree to which water management is an issue in their conservation.

Overall, it was concluded that conservation of the *Chara* beds was largely a matter of water level management. A key unknown factor was the degree to which the algal beds could move with shifts in lake levels. The exposure of beds during rapidly declining summer levels indicated that the upper margins of the beds did not shift with increased wave action within time periods of weeks, but may shift over several months. Rapid exposure of the beds would undoubtedly have a significant impact on resident fauna. Since damming, Great Lake levels have exhibited major long term peaks which are correlated with the Southern Oscillation Index (Harris, Davies et al. 1988). It was not known however if the lower margins of the beds would shift in response to light limitation during longer term shifts in lake level.

Davies and Cook (2000) conducted a survey designed to address the following questions:

1. what was the current status and position of the known major *Chara* beds in Great Lake in 1999? and
2. had the beds moved significantly (in elevation) and what are the implications for water management?

That dive survey was conducted in summer, late 1999, to establish the upper and lower depth (altitudinal) limits of the five major *Chara* beds at three locations within each bed. In addition, a single transect was established in the centre of each bed. At each 8 m interval, % algal cover, mean algal height and water depth to the substrate were recorded. No faunal sampling was conducted.

This survey was conducted following a period of high lake levels between 1996 and 1999. They concluded that:

- the beds had extended their depth range and area up the shore profile since 1987;
- that the upslope movement of algal beds was relatively slow (1 - 2m elevation per year).

The survey reported here, conducted in April-May 2001, re-assesses the status of the *Chara* beds, and attempts to quantify their rate of movement as lake levels change. It also assesses the conservation significance of the beds for the species of macroinvertebrate and fish unique to Great Lake, and listed under the Tasmanian Threatened Species Protection Act (1995). The report then explores the need for changes in water management required to maintain the *Chara* beds and the fauna dependent on them.

2. Methods

2.1 Algal bed survey

All previously known major algal beds were surveyed in February 2001. Surveying was conducted by scuba/snorkel diving along fixed transects, with locations shown in Table 1 and on Figure 1. Water depth, % algal cover, dominant algal height and dominant substrate were recorded at 5 m intervals from water's edge to the deepwater limit of the algal bed. The limit was determined by a decline to < 10% cover.

In addition, the number of fish and shrimp (*Paranaspides*) were counted along each 5 m interval swum along each transect. Fish were visually identified as either *Paragalaxias* or *Galaxias*.

Three transects were swum in the major algal bed in each embayment. The transects were spaced so as to be approximately ¼, ½ and ¾ of the distance laterally along the bed. Additional 'visual' transects were swum to locate the lateral margins of each bed, and to check for continuity of each bed between the three intensive transects.

2.2 Benthic faunal survey

Four locations were sampled in the mid-depth of each *Chara* bed, and at the same depth on neighbouring non-weed bed areas in each of four embayments – Elizabeth bay, Reynolds Island (southeast shore), Becketts Bay, and Sandbanks Bay. At each sampling location, six sample units were taken of the benthic fauna, and the resulting material pooled to form a single sample from each location. Each sample unit consisted of a modified 500 micron mesh surber sampled operated by a diver, with a sampling area of $0.09/m^2$, and sampling was conducted by hand disturbance of the benthos with manual washing of the suspended material through the net.

All samples were preserved with 10% formalin. Samples were processed as follows:

- the entire sample was sorted for fish and *Paranaspides* and phreatoicids;
- the sample was then subsampled to 20% in a Marchant box subsampler;

- the 20% subsample sorted completely and all taxa identified and counted for all taxa (except nematodes which were too numerous to sort and count within the time available).
- all taxa from the 20% sub-sample were then identified to family level (except for Turbellaria, Annelida, Hydracarina, and the crustacean groups: Copepoda, Isopoda, Janirids, Ostracoda, Cladocera, Chydorid, Syncarida, Mecoptera).

2.3 Electrofishing and fyke netting survey

Due to the low level of the lake during summer-autumn, a comparison of the fish fauna was attempted of *Chara* and non-*Chara* areas in 15 locations, by conducting wader-operated backpack electroshocking of shoreline sections between 0.5 and 0.8 m depth. Standard runs of ca 20 min shocking time were conducted at each site. In addition, a fyke net was set overnight at each sampling location, parallel to the shore. All fish caught were identified and counted prior to release. Presence of *Chara* was noted at each sampling location.

2.4 Data analysis

2.4.1 Algal surveys

Plots of algal distribution across bed profiles were prepared for all transects. Distributions of algal cover and height were plotted against depth and substrate type. Contour plots of fish and shrimp densities against algal cover and depth were also prepared. ANOVA was used to assess the significance of any differences in % algal cover between substrate types.

Algal bed distribution was compared between the surveys conducted in 1987, 1999 and 2001 by calculating changes in mean depth and altitude of the upper and lower margins of major algal beds in Sandbanks Bay, Reynolds Island, Becketts Bay, Elizabeth Bay and Muddy Bay and Todds Corner. The lower margins for the beds in Canal Bay were not comparably defined between 1999 and 2001 and could not be formally compared. In addition, the small bed in Swan Bay was not surveyed in 2001, and the bed in Little Bay (previously undetected in the 1987 survey) was only surveyed in 2001.

Trendlines were fitted to the bed profiles of all *Chara* bed transects in Sandbanks Bay, Reynolds Island, Becketts Bay, Elizabeth Bay and Muddy Bay, Todds Corner, Canal Bay and Little Bay. Regression equations for these trendlines, along with lateral widths of each bed estimated from the visual transect observations, were then used to derive a relationship between the total area of *Chara* bed in Great Lake and altitude, for the 2001 survey. This area is an underestimate as it does not take into account the smaller beds known to exist in isolated protected areas (such as Grassy Pt, Grassy Bay, Alanvale Pt and Brandum Bay), but is estimated to represent over 80% of the total area in the Lake.

2.4.2 Benthic fauna

ANOVA (two-factor) was used to assess the significance of any differences in density of fish, *Paranaspides* and Phreatoicids between habitat type (*Chara* vs rocky bed) and between embayment (four embayments). These analyses were also conducted to assess differences in taxon richness and total abundance of benthic macroinvertebrates (excluding shrimp and worms).

Table 1. Location of transect sites, Great Lake, surveyed between 28/4 and 4/5/2001.

Site	Site Name	Shore margin		Deep margin	
		Easting	Northing	Easting	Northing
Elizabeth Bay	Elizabeth Bay East	480542	5362965	480597	5362759
	Elizabeth Bay Lateral Margin 1	481130	5363031		
	Elizabeth Bay West	480312	5362100	-	-
Beckett's Bay	Beckett's Bay Centre	479773	5353994	479820	5353879
	Beckett's Bay 1	478650	5352560	478634	5352693
	Beckett's Bay Lateral Margin 1	478477	5352590		
	Beckett's Bay 2	478530	5353373	478549	5353358
Muddy Bay	Muddy Bay 1	481718	5360500	481707	5360354
	Muddy Bay Lateral Margin 1	481826	5359745		
	Muddy Bay 2	482355	5360608	482185	5360429
	Muddy Bay 3	482115	5360092	481980	5360131
Canal Bay	Canal Bay 1	475057	5362541	475144	5362353
	Canal Bay 2	475813	5362340	475755	5362213
	Canal Bay 3	476318	5362470	476325	5362316
	Canal Bay Visual 1	476325	5362316	476312	5362198
	Canal Bay Visual 2	476312	5362198	476240	5362062
	Canal Bay Visual 3	476494	5362438	476506	5362307
	Canal Bay Visual 4	476687	5362465	476723	5362354
Reynolds Island	Reynolds Is. 1	476719	5366004	476797	5365889
	Reynolds Is. Lateral Margin 1	476719	5366004		
	Reynolds Is. 2	477597	5366221	477620	5366065
	Reynolds Is. 3	478213	5365710	478127	5365652
	Reynolds Is. Visual 1			476594	5365738
Todd's Corner	Todd's Cnr. Sth. 1	481585	5354742	481693	5354890
	Todd's Cnr. Sth. Lateral Margin 1	481523	5354839		
	Todd's Cnr. Sth. 2	482184	5354030	-	-
	Todd's Cnr. Sth. 3	482398	5353515	482523	5353587
	Todd's Cnr. Sth. Visual 1	482523	5353587	482558	5353641
	Todd's Cnr. Sth. Visual 2	482083	5354596	482113	5354666
	Todd's Cnr. Nth. 1	482820	5354824	482671	5354850
	Todd's Cnr. Nth. 2	482922	5355566	482859	5355385
	Todd's Cnr. Nth. 3	481693	5355361	481767	5355243
	Todd's Cnr. Nth. Lateral Margin 1	481600	5355270		
Sandbanks Bay	Sandbanks 1	485141	5369806	485206	5369713
	Sandbanks Lateral Margin 1	485206	5369713		
	Sandbanks 2	484637	5369833	484678	5369774
	Sandbanks 3	484036	5369477	484209	5369402
	Sandbanks Visual 1	485390	5368984	485271	5368923
	Sandbanks Visual 1	485381	5369584	485318	5369570
	Sandbanks Visual 3			484093	5368955
Brandum Bay	Brandum Bay Visual 1	473179	5370275	473277	5370262
Little lake Bay	Little Lake Bay Lateral Margin 1	475843	5373555		
	Little Lake Bay Lateral Margin 2	476051	5374284		
	Little Lake Bay 1	475744	5373634	475811	5373710
	Little Lake Bay 2	475600	5374022	475779	5373952
	Little Lake Bay 3	475938	5374283	475988	5374153
	Little Lake Bay Visual 1	476348	5374198	476371	5374089
Grassy	Grassy Bay Visual 1	477234	5373123	477284	5373262
	Grassy Point Visual 1	476495	5372711	476340	5372636
Sth. Grassy	Sth. Grassy Point Visual 1	477498	5371748	477336	5371656
Alanvale Pt	Alanvale Point Visual 1	473924	5371385	473999	5371408

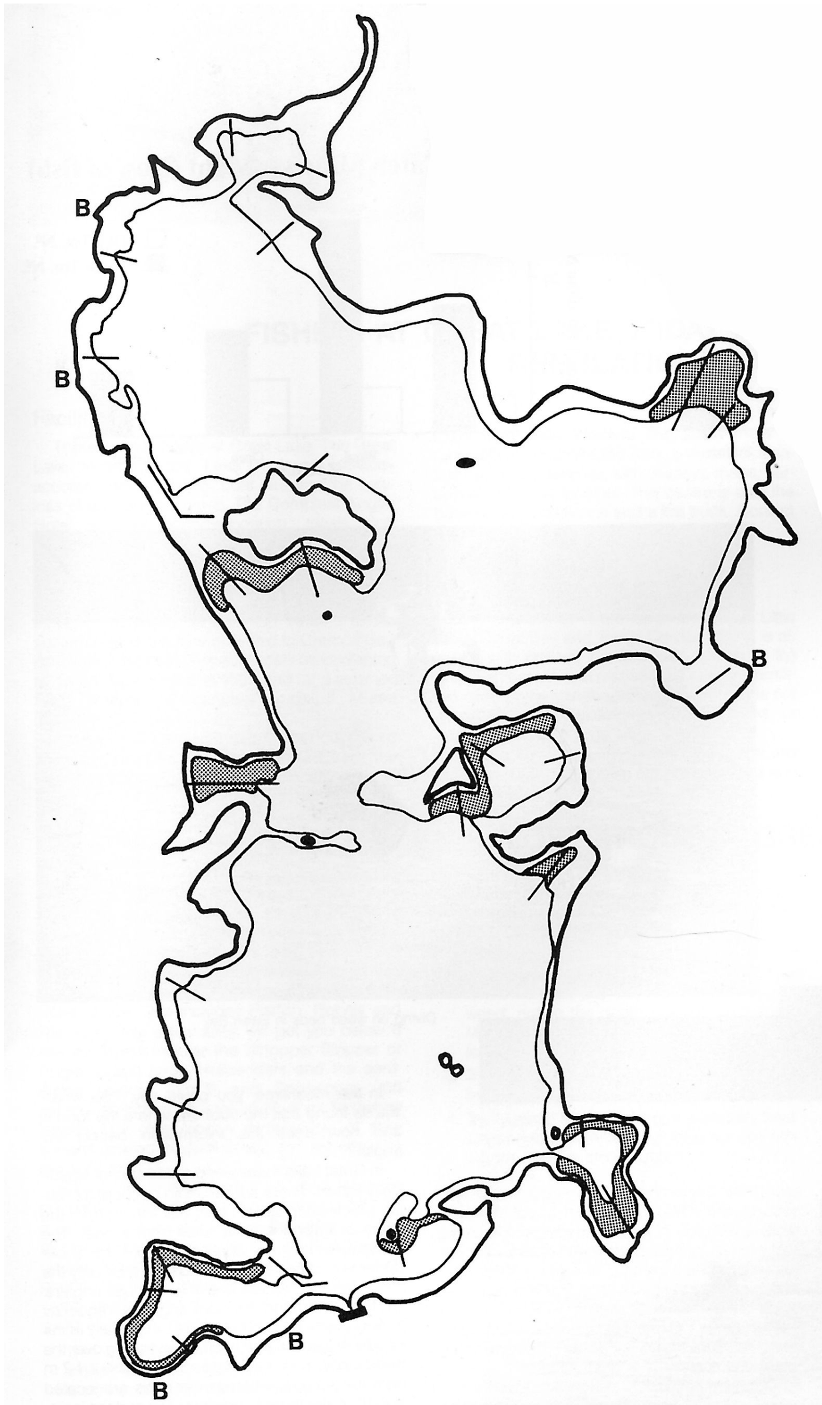


Figure 1. Map of Great Lake indicating position of transects surveyed in May 2001, as well as the position of known major algal beds.

3. Results

3.1 Algal survey

Extensive algal cover was observed at all previously surveyed transects at which algal cover had been noted. Thus all major beds in Sandbanks Bay, Reynolds Island, Becketts Bay, Elizabeth Bay and Muddy Bay, Todds Corner and Canal Bay still maintained substantial areas of *Chara* bed, with a variety of additional macrophyte species observed in Todds Corner (including *Potamogeton* and *Elodea canadiensis*). Algae were again observed at Brandums Bay. New areas of algal cover, were observed in Little Bay and Grassy Bay, as well as south of Grassy Point at Alanvale Bay. These are not believed to represent major areas of *Chara* but should be surveyed in detail in future surveys. The areas of *Chara* bed identified from the 2001 survey are shown in Figure 1. Overall, the survey supported the findings of the 1987 and 1999 surveys in the distribution of algae, with the addition of several new areas. The dominant areas of *Chara* bed are still associated with shores that are moderately to highly sheltered from north-westerly to westerly wind action.

Most *Chara* beds had dense cover for much of their extent, frequently ranging up to 80 - 100%, especially in Elizabeth, Canal, Sandbanks and Little Bays, Reynolds Island and Todds Corner. Height was variable but generally between 10 and 20 cm, with maximum heights of around 30 cm. *Potamogeton* in Todds Corner reached greater heights (up to 50 cm), and tended to occur at greater depths than the *Chara*, particularly in the southern and eastern corners of the bay.

The upper margins of all *Chara* beds surveyed were associated with the water's edge, with most weedbeds showing signs of extensive stranding of *Chara* upslope on newly dewatered substrate. Thus, the declining water levels during summer 2000/01 had resulted in the loss of *Chara* habitat through exposure. The extent of loss is discussed below (Section 3.3). The upper margins at the water edge of a number of beds in slightly exposed situations were associated with reduced cover within 1m depth of the shoreline. Beds on highly sheltered shores tended to maintain high *Chara* cover right to the water's edge. It is apparent that wave action at the shoreline in less sheltered conditions limits *Chara* development to a depth of around 1 m.

The elevations of the deepwater margins of all *Chara* beds are shown in Table 2. The majority of *Chara* beds had deepwater margins (i.e. with cover falling to less than 10%) at around 1022 m altitude (a mean of 1021.8 m, equating to 5.3 m depth in late April 2001), see Figure 2. The depths of these margins were consistent with depths observed in 1999 and 1987, but were significantly higher in elevation (altitude).

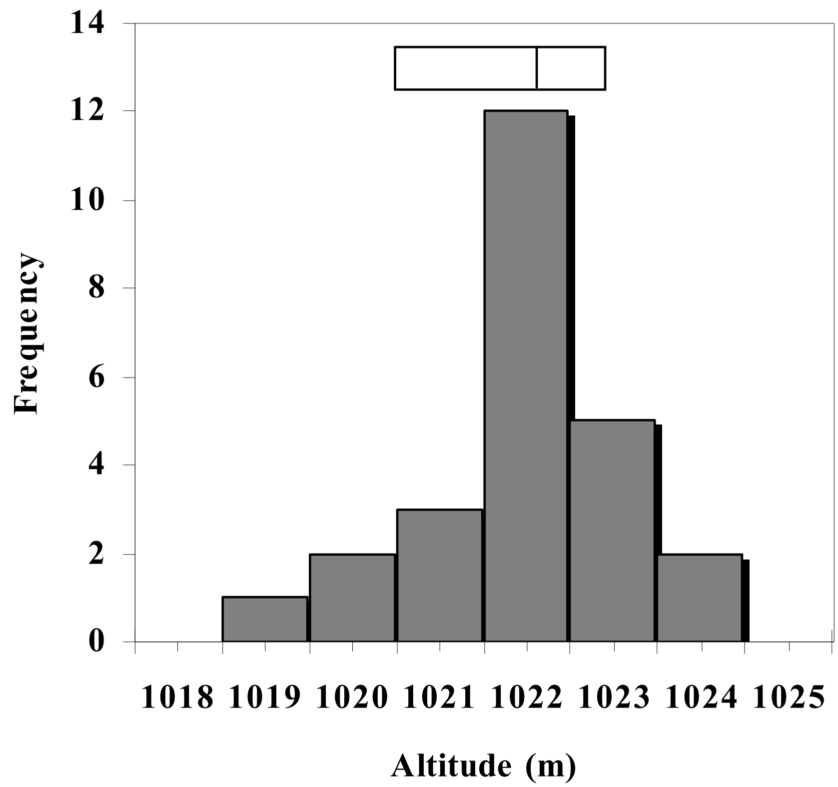


Figure 2. Frequency distribution of altitude of lower margins of *Chara* beds derived from all transects in the seven bays surveyed in 2001. Also shown as a box-plot (center-line and outer margins of box = median, 25 and 75 percentiles).

This, combined with lower altitudes observed for peak *Chara* cover in 2001, indicated that all beds had moved significantly downslope (to lower attitudes) in 2001 since 1999, associated with decreasing Great Lake water levels. This is discussed in more detail below.

The distribution of algal cover with depth is shown in Figure 3, across all transects. The variable density at depths < 1m is associated with the variable influence of wave action on shore algal development, as discussed above. A peak in higher cover at

Table 2. Elevations of deep water (deepwater) margins of *Chara* beds in eight embayments in Great Lake, surveyed between 28/4 and 4/5/2001.

Bay	Site	Elevation (m)
Todd's Corner	Nth. Transect 1	1022.47
	Nth. Transect 2	1024.67
	Nth. Transect 3	1023.87
	Sth. Transect 1	1024.87
	Sth. Transect 2	1025.17
	Sth. Transect 3	1024.57
Sandbanks Bay	Transect 1	1024.97
	Transect 2	1024.87
	Transect 3	1025.37
Reynolds Is.	Transect 1	1023.97
	Transect 2	1025.27
	Transect 3	1023.67
Canal Bay	Transect 1	1026.32
	Transect 2	1022.4
	Transect 3	1021.5
Muddy Bay	Transect 1	1024.47
	Transect 3	1024.87
Beckett's Bay	Transect 1	1024.67
	Transect 2	1024.57
	Transect 3	1024.67
Elizabeth Bay	Transect 1 (West)	1026.57
	Transect 2 (East)	1024.37
Little Bay	Transect 1	1025.17
	Transect 2	1025.07
	Transect 3	1024.07

depths between 2 and 4 m depth was observed for most transects, along with a reduction in cover at depths from 4.5 to 6 m associated with the lower bed margins.

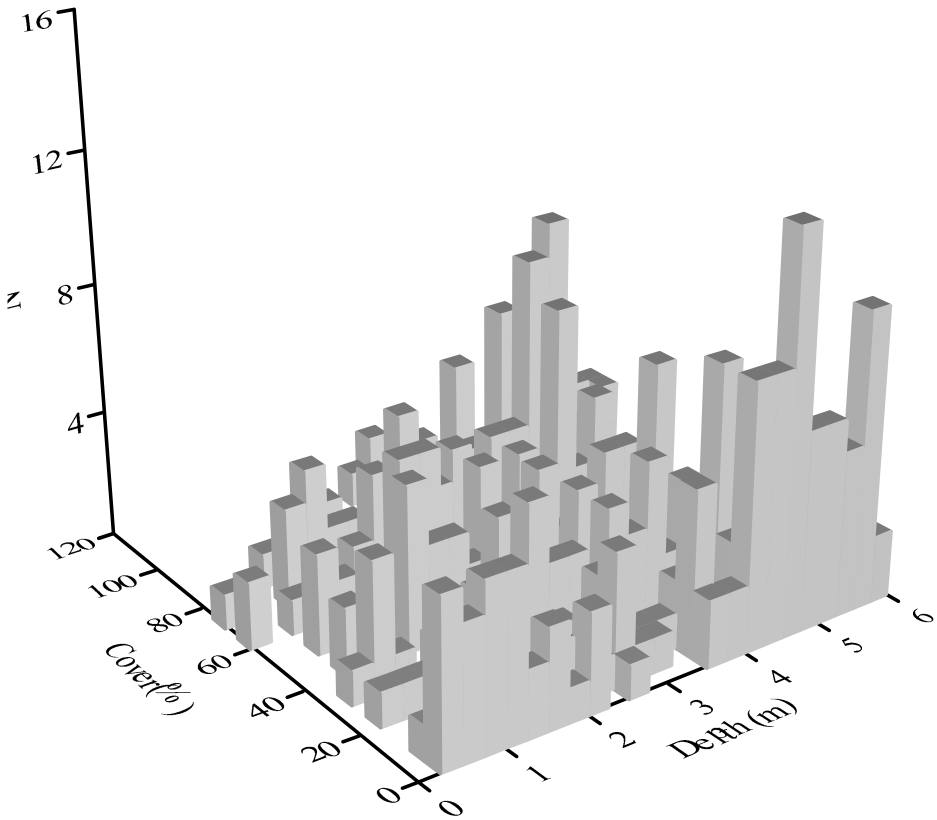


Figure 3. Distribution of algal cover across depth for all transects in Elizabeth, Canal, Sandbanks and Little Bays, Reynolds Island (SE shore) and Todds Corner. Note the variable density at depths < 1m, the general peak in higher cover at depths between 2 and 4 m depth, and the reduction in cover at depths from 4.5 to 6 m.

The distribution of algal height with depth and cover is shown in Figure 4. *Chara* height was generally greatest at greater depth and cover.

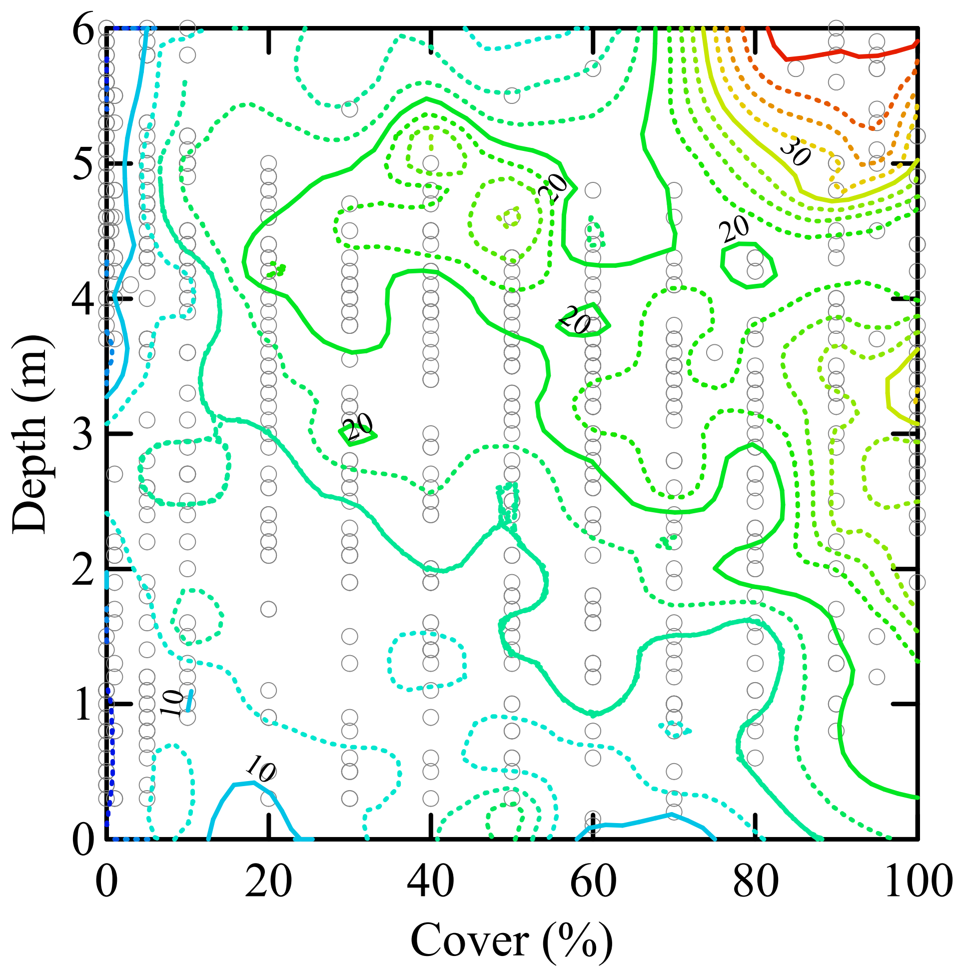


Figure 4. Distribution of algal height with water depth and % cover in major Great lake *Chara* beds. Note general trend to greater height at greater depth and cover, greater heights (20 – 40 cm) associated with dense cover (> 80%) for all depths > ca 2m, with some high (> 20 cm) algae at intermediate cover (20 - 70%) at depths between ca 3 and 5.5 m.

Algal cover was most pronounced on silt substrates (Figure 5) and there was a strong association between silt, either alone or among small boulders, and high (>35%) mean *Chara* cover. Silt dominated substrates, including silt associated with small boulders, was associated with significantly greater *Chara* cover than mud, pebble or gravel substrates (all $p < 0.002$ by ANOVA). Flat rock substrate (often with isolated patches of silt on the surface) was intermediate in cover, while consolidated soil substrates, while uncommon, had high algal cover.

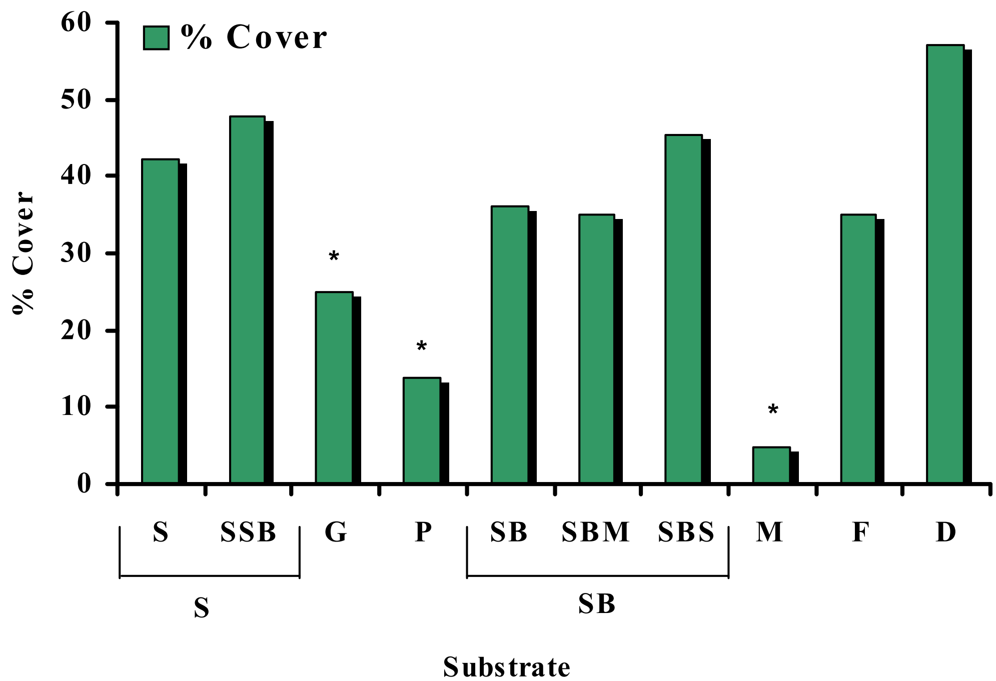


Figure 5. Mean % cover of *Chara* by substrate type within *Chara* beds of Great lake. S = silt, SB = small boulders, G =gravel, P = pebble, M = mud, F = flat rock, D = packed soil/dirt, SSB = sand and small boulder, SBM and SBS = small boulder and mud/silt. Asterisks indicate significantly lower cover than at other substrates.

3.2 Fish, *Paranaspides* and Phreatoicid distributions

3.2.1 General observations

Phreatoicids were present in all four sampled bays (Becketts, Elizabeth and Sandbank Bay and Reynolds Island), but were highly patchy in distribution, both between sample locations within habitats, and also between bays. The overall mean abundance was 27/m^2, with a peak abundance of 623/m^2 (at one sample location in Elizabeth Bay). A significant number of sampling locations did not contain phreatoicids (6 out of 32 locations).

A total of six species were observed, four of which are listed under the TSPC Act (1995), indicated below by an asterisk:

*Onchotelson brevicaudatus**	Smith, 1909
*Onchotelson spatulatus**	
Mescocanthotelson setosus *	Nicholls, 1944
*Mescocanthotelson tasmaniae**	Thomson, 1894
Mescocanthotelson fallax	
Mescocanthotelson decipiens	

The most common species across all locations sampled was *M. setosus*, occurring in 15 of the 32 sampling locations, and in all four bays. *M. tasmaniae* was only found in Becketts Bay, on rocky bed habitat, while *O. spatulatus* was only found in Elizabeth Bay (in both habitat types). *M. decipiens* and *M. fallax* were the least common and least abundant, occurring in only four sampling locations across two bays (Sandbanks and Becketts).

No specimens of *Uramphisopus pearsoni* Nicholls, 1943, another species listed under the TSPC Act were observed. Recent collections by Buz Wilson (National Museum of Sydney) suggest that this species is very rare within the lake, and appears currently restricted to soft sediments on the original lake bottom.

Paranaspides lacustris was relatively abundant, particularly given the likely relatively low efficiency of capture of this mobile species, with a mean abundance of 8.9 and 0.86/m^2 in *Chara* and rocky bed habitats, respectively. A maximum abundance of

211/m^2 was observed at one sampling location in Becketts Bay. Again, diver estimated abundances were much lower, with a mean of 0.05/m^2 of *Chara* bed area observed. Diver observations indicated that *Paranaspides* was widespread - being present at 26.8% of locations observed within *Chara* beds.

Benthic sampling in both *Chara* and rocky bed habitats resulted in the collection of substantial numbers of fish, all of which were identified as *Paragalaxias dissimilis*. Mean densities were 4.98 and 1.61/m^2 in *Chara* and rocky bed habitats respectively. *P. dissimilis* was found in 20 of the 32 sampling locations, and occurred in both habitats in all bays. Diving observations indicated much lower densities, with a grand mean of 0.015 *Paragalaxias*/m^2 of *Chara* bed area observed, reflecting the much lower efficiency of visual counts of this benthic and cryptic species. Diver observations indicated that *Paragalaxias* present at 11.8% of locations observed within *Chara* beds.

The shoreline electrofishing and fyke netting survey was conducted in shallow waters < 1 m deep, and therefore in the shore zone where *Chara* is generally not well developed due to local wave action. The sites selected for sampling did not allow formal evaluation of differences between embayments. Therefore, comparisons of *Chara* bed and rocky substrate habitats is not possible with these data. The data (Tables 3 and 4) do show that there is a reasonably high abundance of native fish in the shallow shore zone, with abundances in the following order of abundance *Paragalaxias dissimilis* >> *P. eleotroides* > *Galaxias truttaceus* > *G. brevipinnis*.

Previous experience (Davies unpub. data) has shown that *Salmo trutta* is not caught efficiently by this backpack electroshocking at Great Lake, due to low conductivities and high visibility, and that fyke netting with standard mesh size does not effectively capture juveniles (0+ to 1+) fish, which are known to be abundant along this shoreline, and its abundance is probably greatly underestimated. Results for *S. trutta* are therefore inconclusive.

Table 3. Fish catches from electrofishing of shore zones at 15 locations in Great Lake on 3/7/2001. All numbers are N fish/20 min battery time. G. = *Galaxias*, P. = *Paragalaxias*, S. = *Salmo*.

Site Code	Site	Habitat	G. brevipinnis	P. dissimilis	P. eleotroides	S. trutta	Total
5	Rainbow Point	R		6.86	4.90		11.76
7	Muddy Bay	RC		65.67	3.98		69.65
8	Tods Corner	RC	4.00	122.00			126.00
11	Beckets Bay	C		10.00	8.00		18.00
13	Little Lake Bay, SW Point	RC	2.87	127.17	1.91		131.95
14	Reynolds Island	RC		5.00	2.00		7.00
15	Little Lake Bay, SW Point	R	1.99	132.12	10.93		145.03
16	Bay north of intake	RC		87.51	7.96	1.33	96.80
19	South Muddy Bay	R		49.59	3.97	1.98	55.54
20	Tods Corner and Shoobridge Island	RC		80.00	10.00		90.00
22	Beckets Bay	R		34.00	4.00		38.00
24	Reynolds Island	RC		24.00	3.00		27.00
25	Elizabeth Bay	RC		15.76	3.94		19.70
25	South of Howell's Island Point, Elizabeth Bay	C		4.00			4.00
32	SW Intake Bay (North)	R		12.00	1.00		13.00
	Mean		**2.95**	**51.71**	**5.04**	**1.65**	**56.90**

Table 4. Fish catches from fyke netting of shore zones at 15 locations in Great Lake on 3/7/2001. All numbers are N fish/24 hr net set time. G. = *Galaxias*, P. = *Paragalaxias*, S. = *Salmo*.

Site Code	Site	Habitat	G. truttaceus	G. brevipinnis	P. dissimilis	P. eleotroides	S. trutta	Total
5	Rainbow Point	R			2.28	1.14	1.14	4.56
7	Muddy Bay	RC						0.00
8	Tods Corner	RC			17.18			17.18
11	Beckets Bay	C			45.03	3.75		48.78
13	Little Lake Bay, SW Point	RC	1.01		4.04	1.01		5.05
14	Reynolds Island	RC			1.12			1.12
15	Little Lake Bay, SW Point	R		1.04	27.97	1.04		30.04
16	Bay north of intake	RC	2.02		8.07	1.01		9.08
19	South Muddy Bay	R			3.07			3.07
20	Tods Corner and Shoobridge Island	RC			11.26	1.02		12.28
22	Beckets Bay	R			13.00			13.00
24	Reynolds Island	RC			4.26	1.06		5.32
25	Elizabeth Bay	RC						0.00
25	South of Howell's Island Point, Elizabeth Bay	C	1.08		7.58			7.58
32	SW Intake Bay (North)	R			3.08			3.08
	Mean		**1.37**	**1.04**	**11.38**	**1.43**	**1.14**	**10.68**

3.2.2 Differences between Chara and rocky beds

Overall densities of Phreatoicids, *Paragalaxias dissimilis* and *Paranaspides lacustris* in *Chara* and rocky bed habitats estimated from benthic sampling in four embayments are shown in Figure 6. There was substantial variability in densities for all three groups, caused primarily by substantial differences between bays.

Two-way ANOVA indicated that densities of all three groups were significantly higher in *Chara* beds than on rocky shores, with means being higher by factors of 10.3, 3.0 and 3.1 for *Paranaspides*, phreatoicids and *Paragalaxias dissimilis*, respectively Tables 5, 6 and 7).

Significant differences in densities between bays were observed for phreatoicids ($p = 0.1$) and *Paragalaxias* ($p = 0.009$), but not for *Paranaspides* (Figures 7, 8 and 9). The differences between habitats were statistically significant for phreatoicids ($p = 0.046$) and *Paragalaxias* ($p = 0.013$), and highly significant for *Paranaspides* ($p = 0.00003$). A significant bay x habitat interaction was also detected for *Paragalaxias*, indicating that differences between *Chara* and rocky bed densities were greatest in Becketts and Elizabeth Bays.

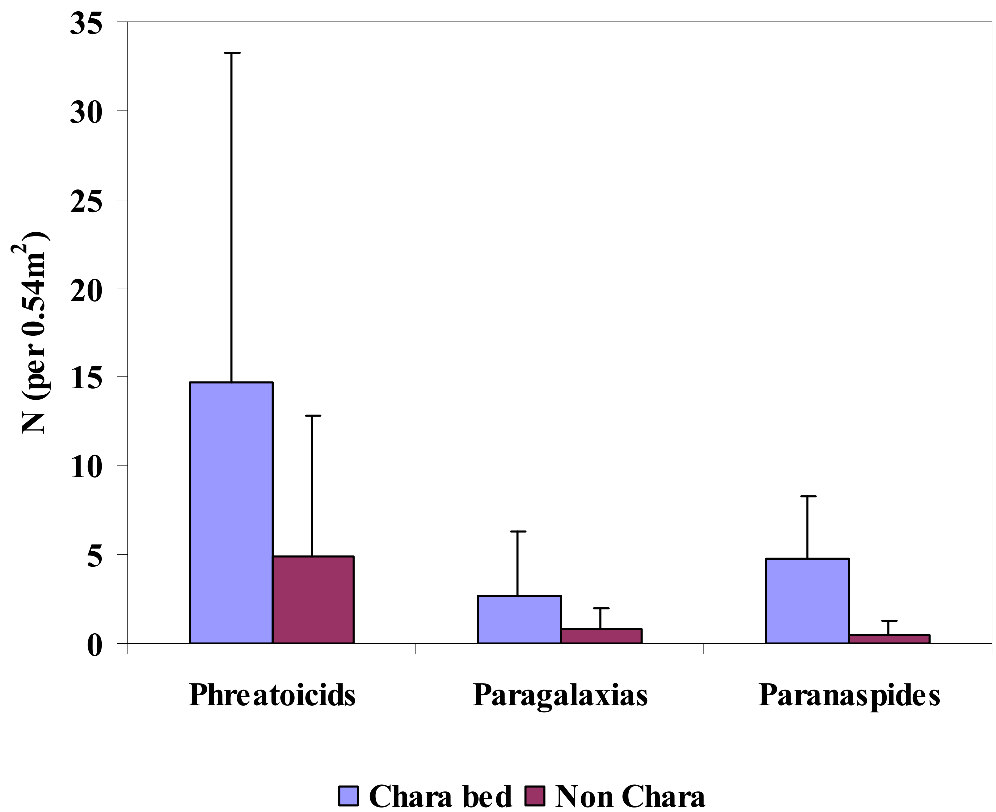


Figure 6. Mean benthic densities of Phreatoicids, *Paragalaxias dissimilis* and *Paranaspides lacustris* observed at four locations in each of four embayments within Great Lake, compared between *Chara* and rocky bed habitats. Bars represent standard deviations.

Table 5. Results of two-way ANOVA of phreatoicid densities in benthic samples from four bays in Great Lake.

N: 31; Multiple R: 0.63; Multiple R^2: 0.398

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Bay	1225.151	3	408.384	2.299	0.104
Habitat	786.444	1	786.444	4.428	0.046
Bay * Habitat	717.924	3	239.308	1.347	0.284
Error	4084.8	23	177.6		

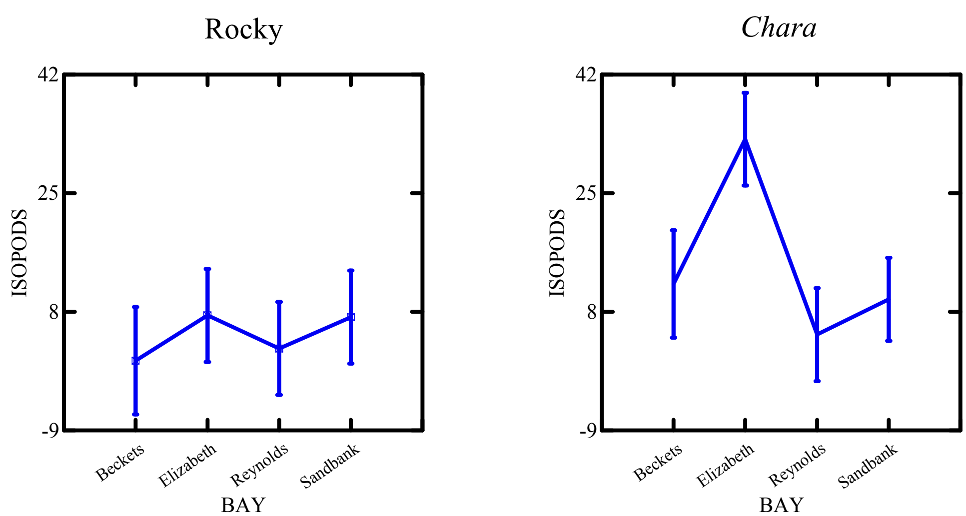


Figure 7. Phreatoicid abundances (least squares means) in *Chara* and rocky bed habitats, by bay. Note differences between bays.

Table 6. Results of two-way ANOVA of *Paragalaxias dissimilis* densities in benthic samples from four bays in Great Lake.

N: 31; Multiple R: 0.763; Multiple R^2: 0.582

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Bay	63.772	3	21.257	4.933	0.009
Habitat	31.638	1	31.638	7.342	0.013
Bay * Habitat	46.099	3	15.366	3.566	0.030
Error	99.117	23	4.309		

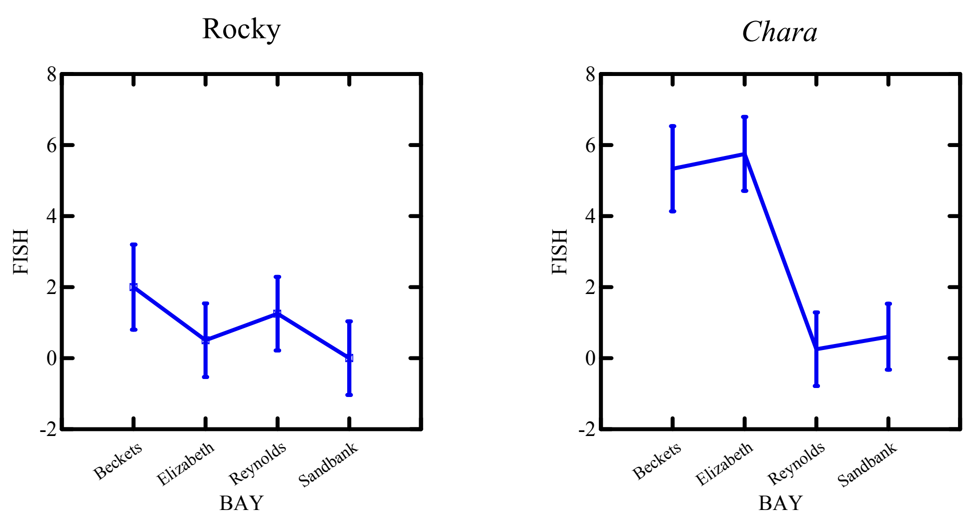


Figure 8. Mean *Paragalaxias dissimilis* abundances in *Chara* and rocky bed habitats, by bay. Note large differences between bays.

Table 7. Results of two-way ANOVA of *Paranaspides lacustris* densities in benthic samples from four bays in Great Lake.

N: 31; Multiple R: 0.771; Multiple R^2: 0.594

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Bay	17.515	3	5.838	0.977	0.421
Habitat	160.240	1	160.240	26.820	######
Bay * Habitat	35.472	3	11.824	1.979	0.145
Error	137.417	23	5.975		

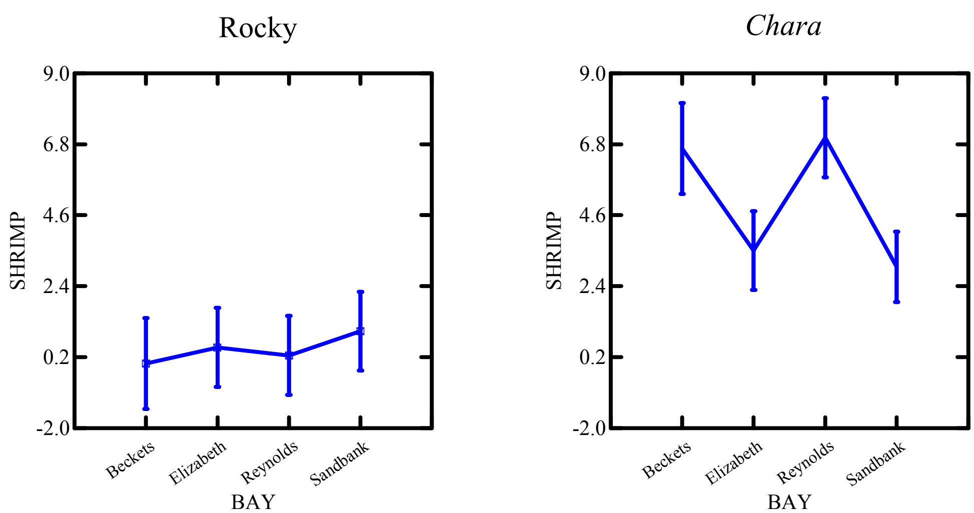


Figure 9. Mean *Paranaspides lacustris* abundances in *Chara* and rocky bed habitats, by bay. Note absence of substantial differences between bays, but large difference between habitat types.

3.2.3 Fish and Paranaspides distributions within Chara beds

Diver estimates of densities of *Paranaspides* and fish were derived for all algal survey transects except those in Elizabeth Bay. These estimates were not accurate, as densities of fish estimated by diving and electrofishing in the same depth and algal cover range were significantly different (diver estimates being lower by two orders of magnitude). In addition, shrimp densities estimated by benthic sampling were significantly higher than those estimated by diver observations. Casual observations by divers of high fish densities under individual rocks (up to 17 *Paragalaxias* being observed under one 30 cm boulder when upturned), suggest that both electrofishing and diver-observations have low efficiency.

However, diver counts were believed to be reasonably consistent across depths and transects, and allowed ready differentiation of *Paragalaxias* and *Galaxias* fish genera. In addition, the trends in densities of fish and *Paranaspides* estimated by divers were not consistent with declining observation efficiency at higher algal cover, indicating that these trends were likely to be real rather than a product of poor visibility with high algal cover. This was facilitated by the tendency for *Paranaspides* to inhabit the upper margins and tops of *Chara* stands.

Paranaspides densities varied with depth and algal cover (Figures 10 and 12), with density increasing with both depth and % *Chara* cover. By contrast, both *Paragalaxias* and *Galaxias* appear to occupy different ranges of depth and algal cover, with *Paragalaxias* appearing to occupy a range of depths and *Chara* densities, but generally at intermediate values (Figures 11 and 13), and galaxias being lower in density and favouring dense algae at shallower depths (Figures 11 and 14).

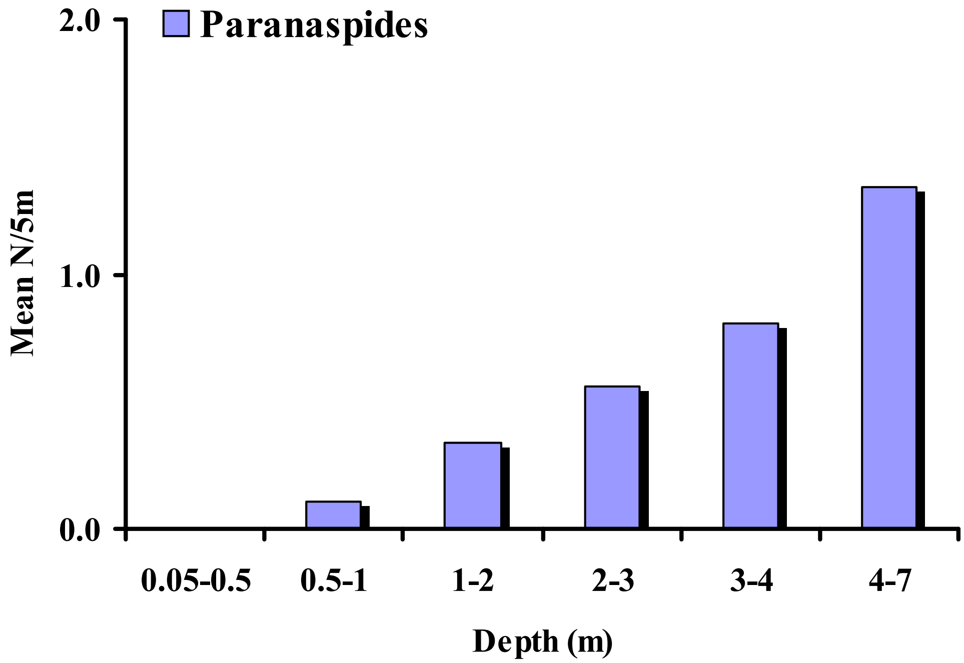


Figure 10. Mean density (number observed per 5 m transect swim) of *Paranaspides* with depth within Great Lake algal beds. Note absence of *Paranaspides* in shallow shore zones.

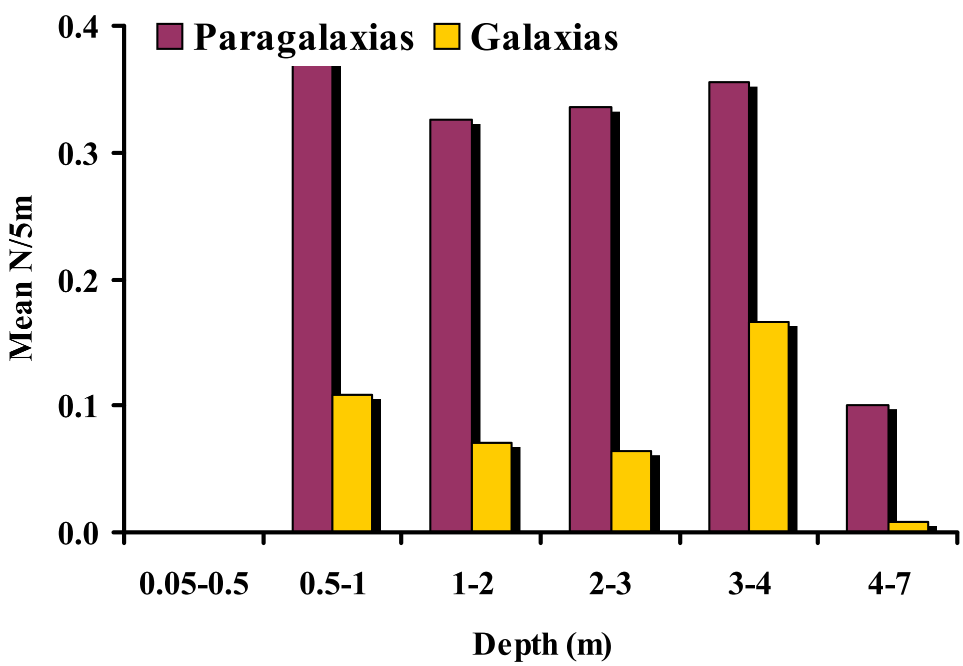


Figure 11. Mean density (number observed per 5 m transect swim) of *Paragalaxias* and *Galaxias* with depth within Great Lake algal beds. Note lower density of *Galaxias*, absence of fish in shallow shore zones, and different depth distributions.

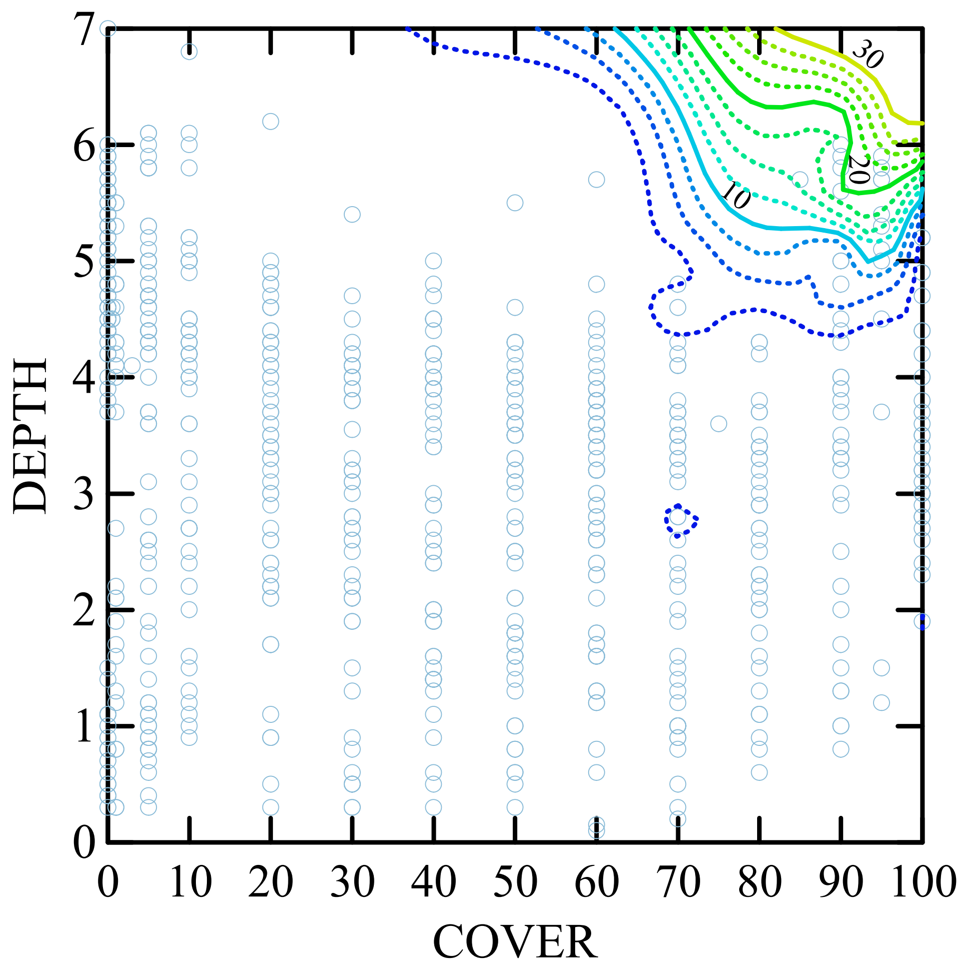


Figure 12. Contour plot of density of *Paranaspides lacustris* in Great lake *Chara* beds against depth (m) and algal cover (%). Note strong association of *Paranaspides* with greater *Chara* cover and greater depth. Circles indicate locations of transect observations from which contours are derived.

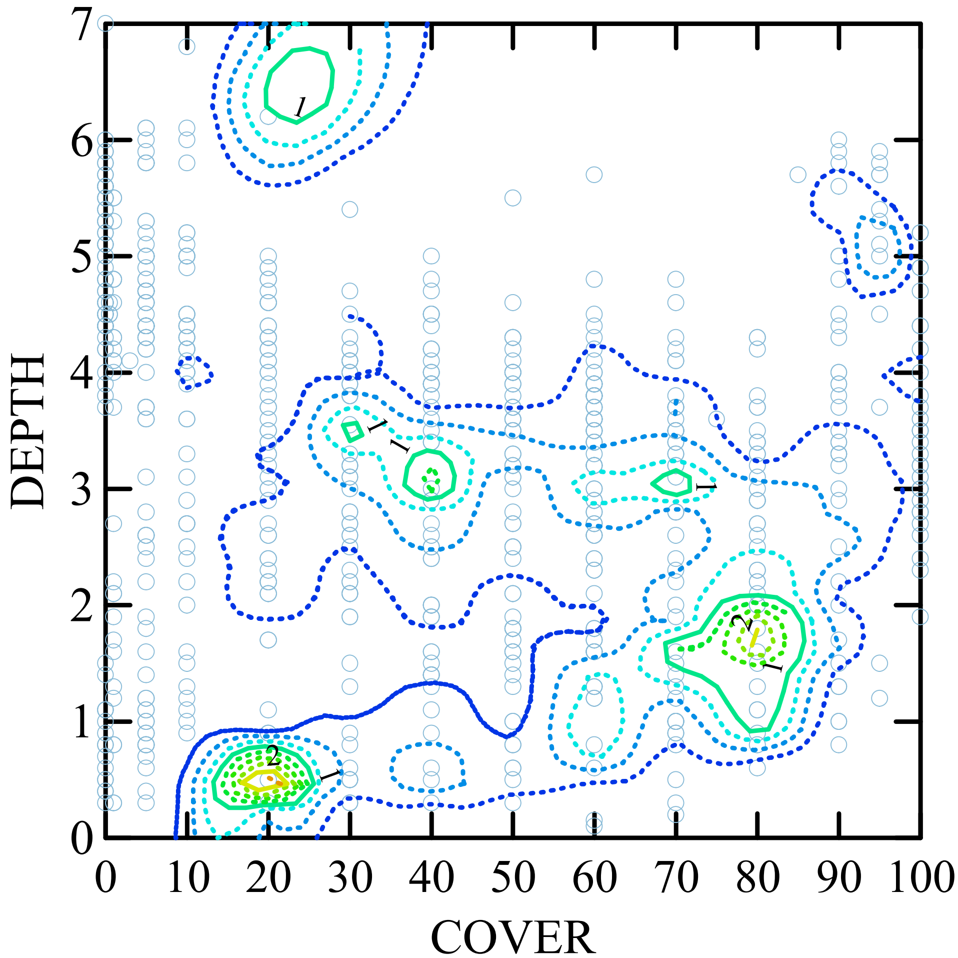


Figure 13. Contour plot of density of *Paragalaxias* (*dissimilis*, see text) in Great lake *Chara* beds against depth (m) and algal cover (%). Note patchy association of *Paragalaxias* with shallow to intermediate depths over a range of *Chara* cover. Circles indicate locations of transect observations from which contours are derived.

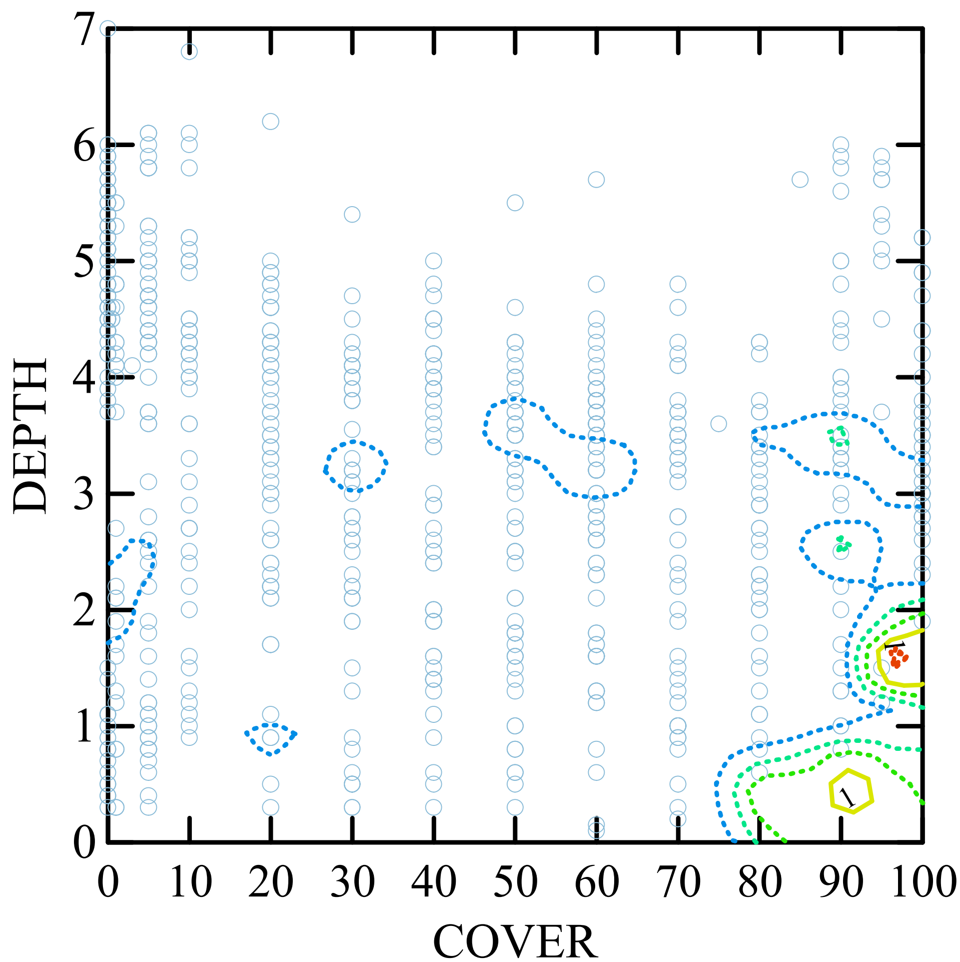


Figure 14. Contour plot of density of *Galaxias* in Great lake *Chara* beds against depth (m) and algal cover (%). Note association of *Galaxias* with greater *Chara* cover at shallow (< 2m) depths. Circles indicate locations of transect observations from which contours are derived.

3.2.4 Associated benthic fauna

Table 8 presents a summary of the benthic macroinvertebrate fauna from *Chara* and rocky bed habitats collected in Elizabeth Bay. The *Chara* bed habitat is significantly more diverse and abundant than the rocky bed habitat ($p < 0.001$ and 0.005, respectively by t-test, $n = 4$), with between 1 and 5 more taxa at 'family' level occurring in the *Chara* (with a mean of 15) than outside it. Thus, in addition to higher abundances of *Paragalaxias dissimilis* and *Paranaspides lacustris*, *Chara* bed habitat is characterised by higher abundances of Turbellaria, Parameletid amphipods, Ostracods, Chironomid and Tanypod larvae, Atriplectid and Leptocerid caddis larvae, Dytiscid diving beetles and Phreatoicids, than rocky substrate. This reflects the siltier and less exposed nature of the *Chara* areas, as well as *Chara*'s more complex microhabitat. There were no taxa that were more abundant in the rocky habitats, with the single exception of the phreatoicid *Mesocanthotelson tasmaniae*, which appears to be restricted to that habitat in Becketts' Bay, as discussed above.

Table 8. Mean abundances of benthic macroinvertebrates (n/0.1m^2) on rocky substrate and *Chara* habitats, Elizabeth Bay, Great Lake, in May 2001. Data does not include *Paranaspides lacustris*.

			Rocky substrate	*Chara*
Platyhelminthes	Turbellaria		1	22
Mollusca	Bivalvia	Sphaeridae	3	24
	Gastropoda	Planorbidae		8
Oligochaetae			140	229
Arachnida	Hydracarina		2	6
Crustacea	Amphipoda	Paramelitidae	2	11
	Copepoda		4	23
	Janirids		10	39
	Ostracoda		1	39
	Cladocera		478	58
Diptera	Chironomidae	Chironominae	11	494
		Orthocladiinae	10	4
		Tanypodinae	1	129
	Trichoptera	Atriplectrididae	2	6
		Leptoceridae		19
		Dytiscidae		4

3.3 Changes in *Chara* bed distribution with lake level

Altitudinal position of beds

It is apparent when comparing the results of surveys in 1987, 1999 and 2001, that the position of the *Chara* beds in Great Lake on the lake margins changes significantly.

The lower margins of the beds are typically between 5 and 8 m below the surface, and this is generally consistent across bays and transects within bays, with a few exceptions. This lower limit is generally not sharp – with algal cover declining gradually over a few metres depth – unless associated with a steep drop-off, as was observed in a number of transects in the 1987 survey. This lower limit also does not appear to be associated with any distinct change in substrate type. Thus, it appears that the lower margins are determined by light limitation.

The upper margins in 2001, as in 1999, were all at the water's edge with areas of stranded algae evident upslope. Under these conditions, as noted above, there is a localised effect of wave energy on the viability of *Chara* near the water's edge which restricts algal growth within ca 1m depth from the edge. The upper limit in 1987 was not associated with the water's edge, and was similar in form to the lower edge i.e. not sharp or distinct, but patchy. The 1987 survey was conducted during a period of rising lake levels, while the surveys in 1999 and 2001 were conducted during a period of sharply declining summer-autumn levels. The upper limit of the *Chara* beds is therefore strongly determined by whether the lake level is rising or falling.

Lateral position of beds

There is no evidence from the 1999 and 2001 surveys that there has been a marked lateral change in the distribution of *Chara* in the main algal beds Sandbanks, Elizabeth, Muddy, and canal bays or at Reynolds Island or Todds Corner. Potentially extensive beds in Little and Grassy Bays were observed in 2001, along with narrow but possibly laterally extensive beds south of Grassy Point and on the western shores near Brandums and Alanvale Bays. Examination of these observations suggests that any such beds probably account for 20% or less of the total *Chara* area within the lake. However, it does suggest that the lateral extent of *Chara* may be dynamic in these more marginal situations. Changes in lateral extent may result from changes in lake level, but also from longer (> 1 year) changes in substrate distribution caused by periods with less intense storms.

Changes between surveys

Inspection of altitudinal changes in position of *Chara* bed upper and lower margins within the six main bays surveyed (Table 2), indicates that:

- the lower margins had shifted to a mean of approx. 2.5 m lower elevation in 2001 than in late 1999;
- the upper margins in both cases were within 1 m of the lake water surface;
- the lower margin observed in late 1999 was some 3.7 m higher in altitude than in 1987.

Table 9. Mean elevations (m) of the upper and deepwater margins of Chara beds in Great Lake as surveyed in May 1987, October 1999 and May 2001. Means for 1999 and 2001 both calculated from transects in Canal, Sandbanks, Elizabeth, Becketts Bays, Reynolds Island and Todds Corner for comparison. 1987 levels estimated from transect observations in Swan, Canal, Elizabeth Bays and Reynolds Island.

	2001	**1999**	**1987**
Upper	1027.03	1032.94	1024.00
Lower	1021.77	1024.26	1020.60

Together with inspection of lake levels, these observations suggest that a maximum rate of migration of *Chara* bed margins is of the order of 2 m elevation per year.

In addition, it is apparent that significant loss of *Chara* habitat has occurred between the late 1999 and May 2001 surveys, with a loss of 68% of the Chara habitat present in late 1999 through dewatering and exposure on the shoreline. An additional 29%

areas was gained by downslope movement of the lower Chara margin, resulting in a net loss of 39% of the Chara present in late 1999, by May 2001. Thus, in a single period of only 18 months, some 40% of this habitat had been lost due to rapid lake level decline.

Relationships between Chara area and altitude

Inspection of the plots of *Chara* bed profiles, shown in Appendix 1, reveals that the profiles are quite varied in slope and extent, and that most profiles are linear, with a number being convex in form.

Curves were fitted to these profiles and areas at different altitude estimated by multiplying distances along each profile against the observed lateral extent of each bed section. Overall area of *Chara* bed habitat in Great Lake at each increment of lake level (altitude) was then estimated by summing each transect-based area across all transects for each altitude. Figure 15 shows the resulting trend of area with lake level, derived from transect observations in 2001. Observations in 1999 indicate that the trend extends essentially linearly to an altitude of 1032 m, with a range as indicated by the dotted lines in Figure 15.

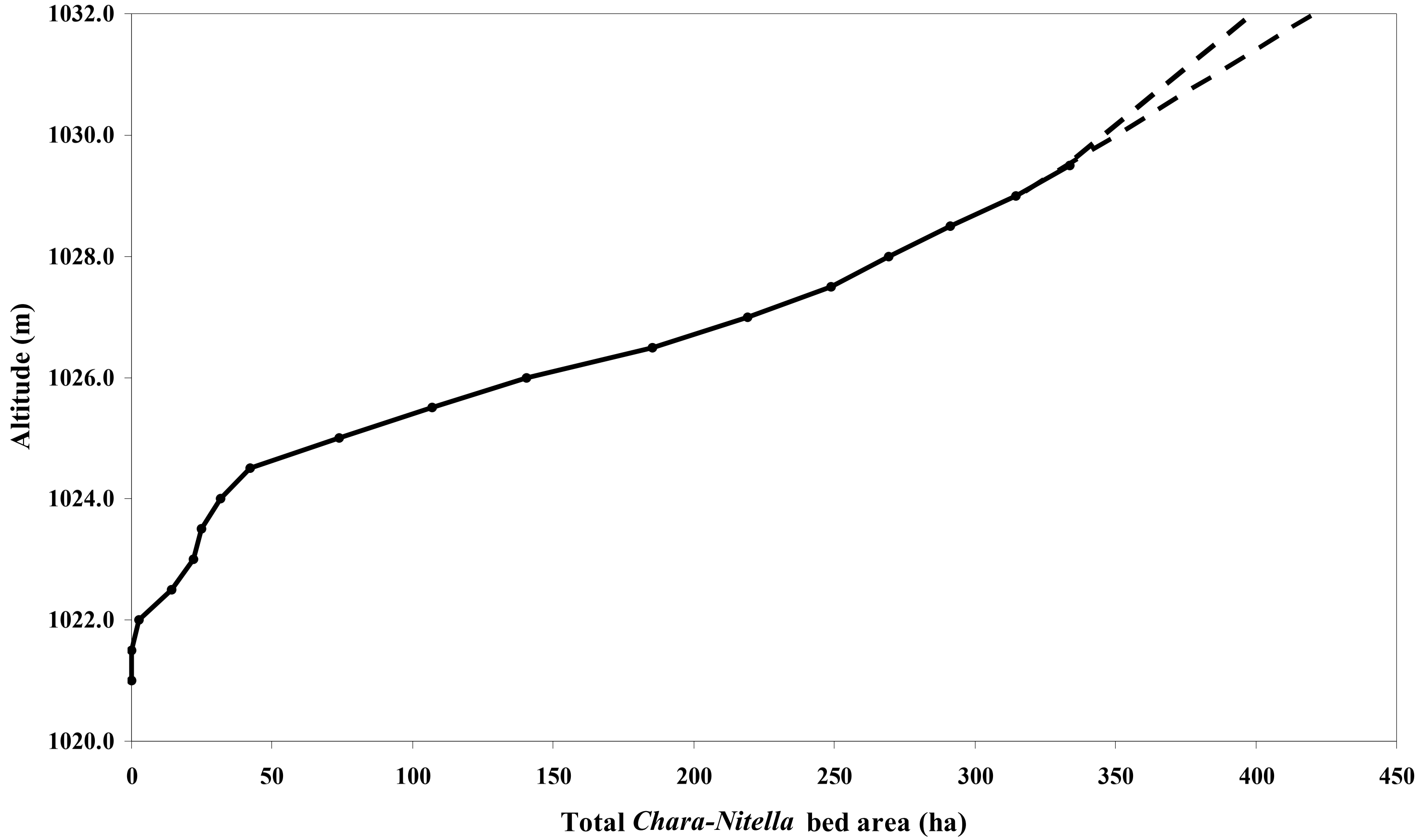


Figure 15. Plot of total area of *Chara* bed habitat within Great Lake against lake level (in m). Solid line = areas estimated from 2001 survey, dotted lines = estimated range between 1029 and 1032 m from 1999 survey.

4. Discussion and Conclusions

4.1 Algal faunal associations

It appears that the *Chara* beds in Great Lake form a significant habitat for a range of macroinvertebrate taxa as well as for *Paragalaxias dissimilis*. The beds contain a significantly more diverse and abundant macroinvertebrate fauna than other benthic habitats on the lake slopes.

We have not compared the fauna of these habitats with that of the main lake bottom, which forms an extensive areas of silt substrate and whose fauna is known to be dominated by worms (Fulton 1981). However, examination of Fulton's Eckman grab data across habitats and with our data indicates that the *Chara* beds contain a significantly more diverse fauna.

In addition, the *Chara* beds are the preferential habitat for the Great Lake shrim*p. Paranaspides lacustris*, with a 10 times greater abundance within than outside the beds. The Great Lake phreatoicids, of which we observed six of the seven species known from the lake, also show a significant preference for the *Chara* habitat. Two species do not however, with *Uramphisopus pearsoni* which we did not collect, occurring only, and rarely, in deeper habitats (Fulton 1981 and B. Wilson 2001, pers. comm.), and *Mesocanthotelson tasmaniae* only being found in samples outside *Chara* beds in Becketts Bay.

Overall, this study confirms that the Great Lake *Chara* beds are of substantial ecological and bioconservation significance. Previous analysis of trout diet and fishery data has suggested that they are also of major significance for sustaining the lake's trout fishery (Davies, Sloane and Fulton 1987, Davies and Sloane 1987).

There is also a second and intriguing pattern to the biological communities within Great Lake. A number of embayments contain distinctive or unique faunas, and this pattern appears to have been sustained since the lake's inundation. Evidence for this includes:

- the isolation of *Onchotelson spatulatus* to Elizabeth Bay (Originally Lake Elizabeth) where it occurs in large numbers, as observed by Fulton (1981) in 1975, and in 2001 (this study);
- the apparent isolation of *Mesocanthotelson tasmaniae* to Becketts Bay (this study);
- the restriction of *Uramphisopus pearsoni* to deep water in the northern part of the Great Lake (Fulton 1981, B. Wilson 2001 pers. comm.);
- greater similarity of faunal composition within bays than within habitat type (this study).

This suggests that an original pattern of faunal distribution within the lake present prior to having its level raised has not completely disappeared, 80 years since the first major raising of its level for hydro generation.

4.2 Algal beds and lake levels

The altitudinal distribution of the Great Lake *Chara* beds is responsive to changes in lake level, with beds migrating upslope during periods of rising level. Beds are exposed during periods of rapidly falling level, but also show an ability to migrate downslope during those periods. We estimate a maximum rate of up and downslope movement of the bed margins of 2 m in altitude per year. Further surveys are required to refine this estimate. It should also be noted that this represents the rate of movement of the bed margins, not the majority of the bed algal cover. Since bed margins are patchy in algal cover, it is likely that migration of peak cover areas up or downslope is likely to be somewhat slower.

It is considered unlikely that *Chara* would become established across the original lake bottom as levels fall below 1020 in the northern lake and 1018 m in the southern lake, due to:

- the rapidity with which levels fall under current operations, limiting the ability of *Chara* to established;
- the loss of shelter from W-NW winds on shorelines at lower lake levels (< ca 1020 m); and

- the need for > 2-3 m depth for *Chara* to establish on the exposed lake bottom.

Thus, an overall 'model' of *Chara* bed dynamics in Great Lake is as follows:

1. *Rising lake levels*

- existing *Chara* beds migrate upslope, with:
  - the upper margin migrating at a maximum of 2m altitude per year as wave stress reduces and silt is deposited on-shore, but always being 1m or more below the water's edge;
  - the lower margins migrating upslope directly in response to decreasing light levels i.e. in synchrony with lake levels on time scales of ca 1 month.
- some lateral extension of *Chara* distribution occurs on sheltered, western/north western shores where silt substrate occurs, depending on antecedent weather conditions.

2. *Falling lake levels*

- existing *Chara* beds migrate downslope, with:
  - the upper margin migrating as wave stress increases and silt is winnowed from the substrate, and/or is exposed due to rapid falling levels i.e. at the same rate as lake levels decline.
  - the lower margins migrating downslope at a maximum of 2m altitude per year in response to increasing light levels at depth;
  - lower *Chara* bed margins limited to an altitude of ca 1016 –1018 m, depending on the depth of water above it;
- some lateral contraction of *Chara* distribution occurs on sheltered, western/north western shores where silt substrate occurs, depending on antecedent weather conditions.

Plots of Great Lake level are shown in Figure 16 for the entire period of record. When the above model of *Chara* bed response to level changes is applied to that record, the positions of the upper and lower margin levels are as shown in Figures 17 and 18. Periods when sections of the *Chara* beds were exposed by falling levels are shown as red bars. The original lake levels are shown in Figure 18, estimated for this study by inspection and measurement of an accurate and detailed landscape of Great Lake by

Eugene Von Guerard, painted in 1874, and comparison with the known lake bathymetry.

Transect data for each of the studied *Chara* beds was used to derive area of *Chara* habitat over a range of lake levels. Values from all embayments were summed to derive total area for the lake, whose relationship with elevation was shown in Figure 15. This relationship is broadly linear and low in slope for much of the lake profile, though area declines steeply at depth. This steeper decline at low elevations is primarily due to the reduction in the number of viable beds at depth rather than a change in lake bed profile. This was therefore adopted as the standard form for the relationship between area of *Chara* and elevation for all depth sequences between 1955 and 2001. A sixth order polynomial regression was applied to this relationship in order to estimate the total area of *Chara* over a range of elevations, as follows:

$$\text{Area (ha)} = 0.0311{*}\text{Alt}^6 - 0.7262{*}\text{Alt}^5 + 5.9336{*}\text{Alt}^4 - 19.907{*}\text{Alt}^3 + 29.761{*}\text{Alt}^2 - 7.6583{*}\text{Alt} - 0.9305 \qquad (\textit{Equation 1})$$

$r^2 = 0.999$. Alt = elevation in m above sea level.

A time series of differences between the elevations of the upper and lower margins of *Chara* in the lake was prepared. Equation 1 was used to convert this into a time series of total *Chara* area for the period 1955 to 2001. Cumulative frequency distributions and time series for these data are shown in Figures 19 and 20. The overall median area was 154 ha, but the plot shows high variability on short (1-3 year) time scales. Excursions below the 20 percentile of the areas, of 75.5 ha, are dispersed throughout the period, with 17 events in total between 1955 and 2001. There were six excursions to very low areas of 50 ha and less. Two long and very intense events resulted from both declining levels and ensuing rising levels associated with dry periods in 1952-56 and 1967-68.

All of these events are also indicated in Figure 17, superimposed on the lake level time series for 1955-2001. The majority of level declines happen within the summer-autumn period. A plot of % change in *Chara* habitat area per 3 month period was therefore also prepared, for the same period (Figure 21).

All of the declines in *Chara* area to levels below the 20 percentile value of 75.5 ha were caused by one of two processes:

1. Sharp declines in lake level at rates exceeding the rate of downslope migration of the lower margin of the *Chara* beds (i.e. > 2m net per year) over a period of two years or more.
2. Rapid rises in lake level following declines to low levels (ca 1020-1022) at rates exceeding the rate of upslope migration of the upper margin of the *Chara* beds (i.e. > 2m net per year).

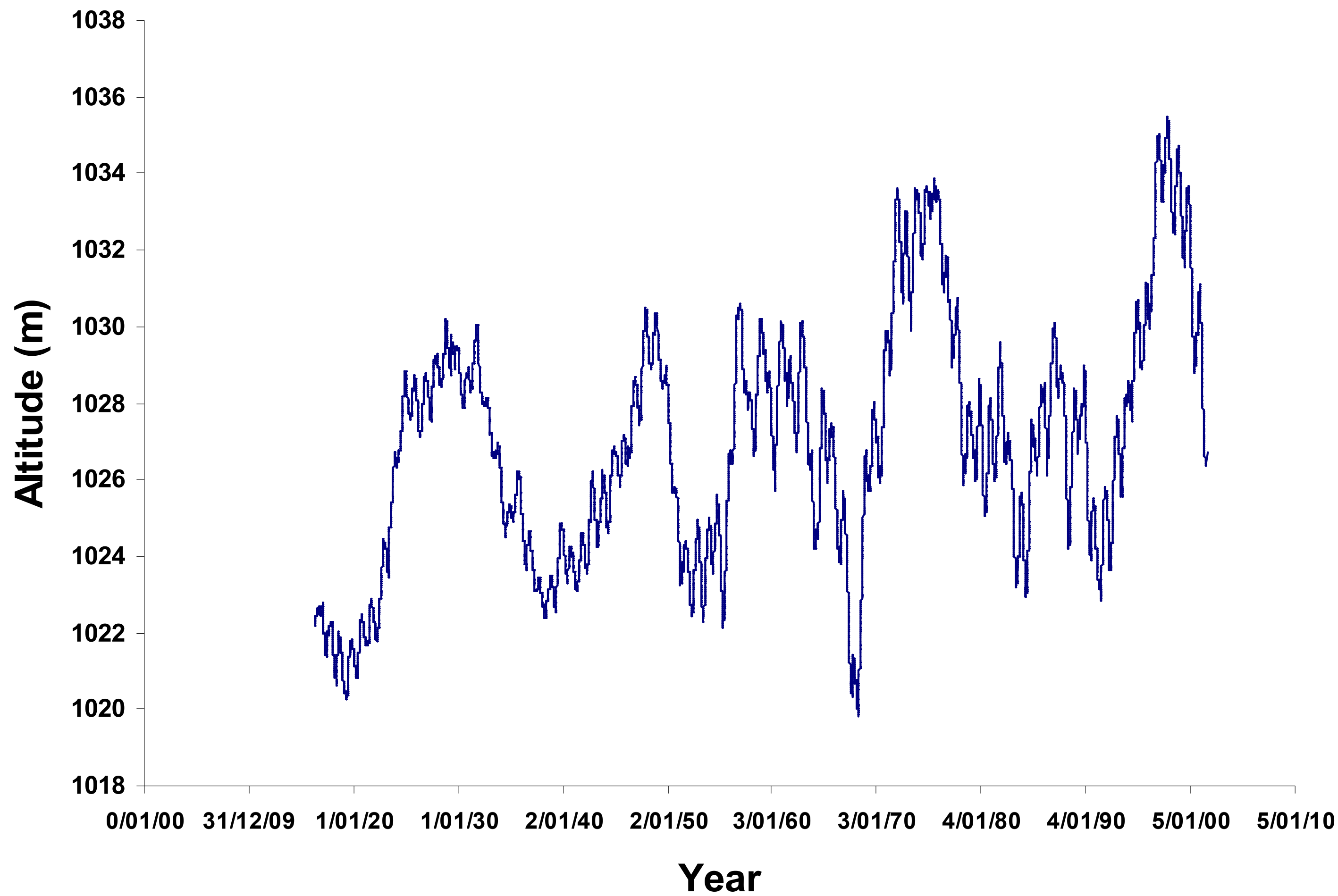


Figure 16. Great Lake levels, historical record to 2001.

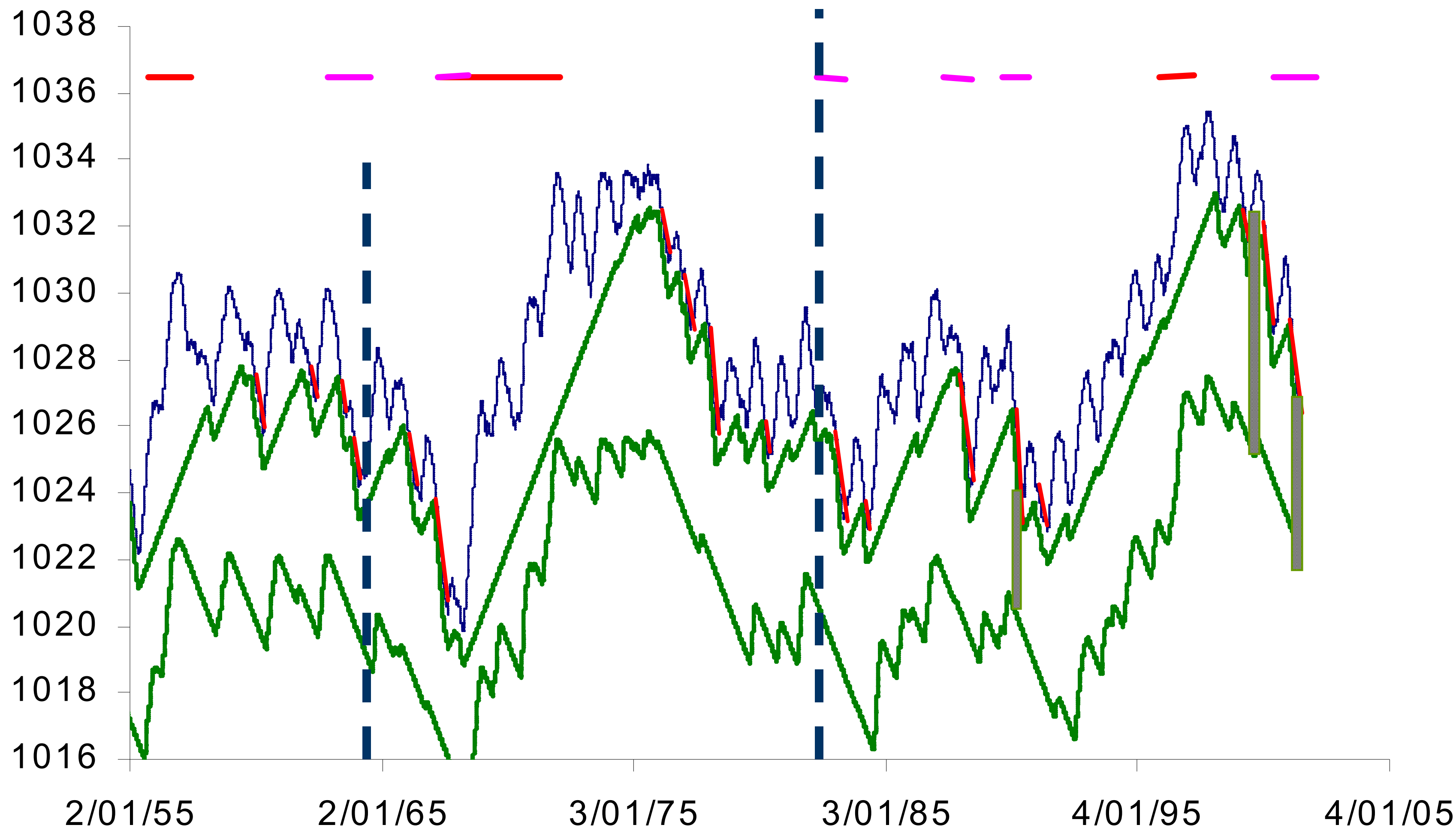
Figure 17. Estimated positions of upper and lower margins of *Chara* beds, Great Lake (green lines), lake levels (blue lines) over the period 1955 - 2001.

Red sloped lines indicate periods of exposure of upper sections of *Chara* beds during rapid drawdown (> 2m /year).

Vertical green bars indicate extent of beds measured during surveys.

Vertical blue dashed lines indicate time and FSL associated with new dam in 1964 and raised dam level from 1982.

Horizontal lines indicate periods of limited *Chara* bed area (< 20 percentile values, see text) caused by rapid level declines (purple) and rapid level rises (red)



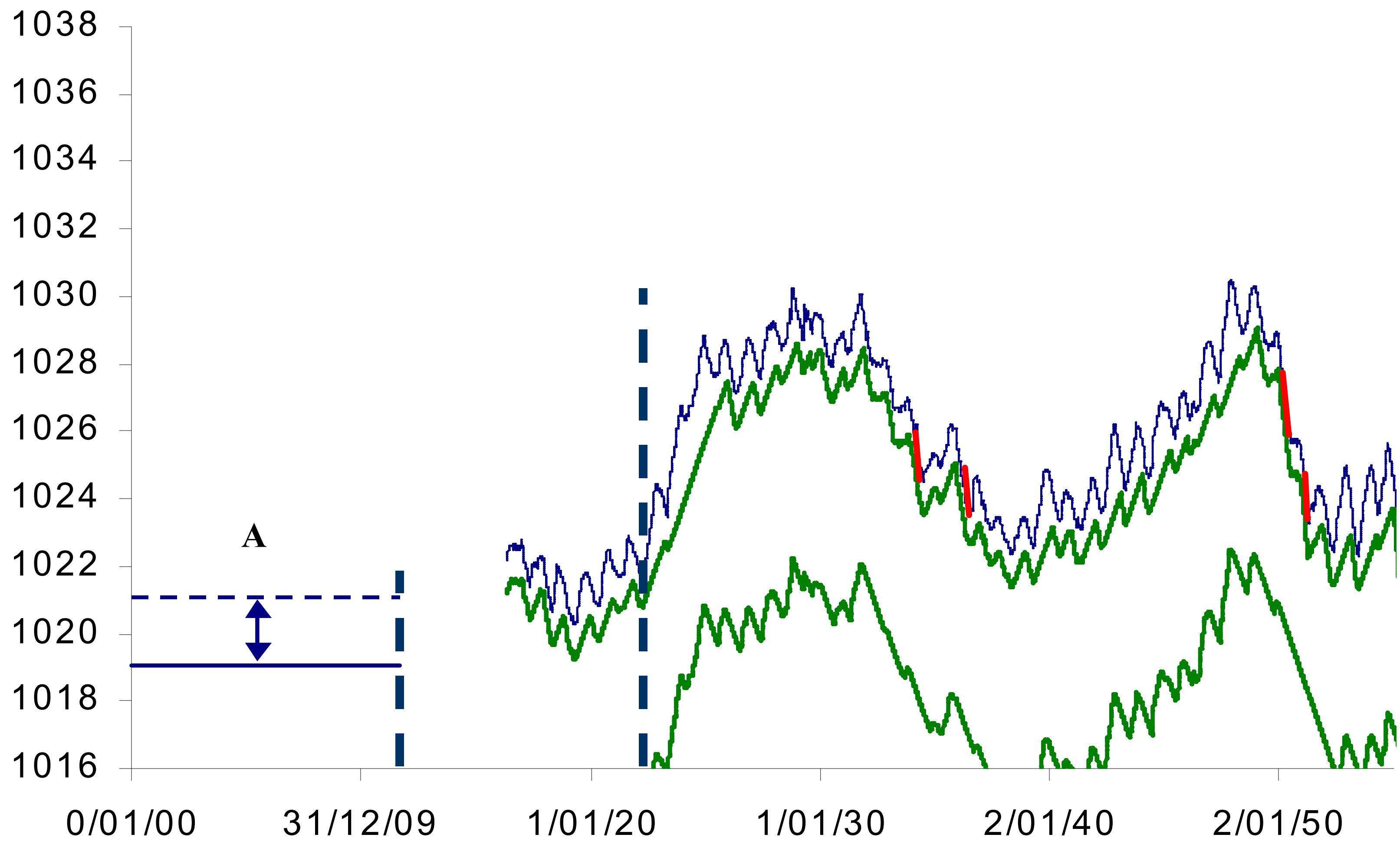
1038
1036
1034
1032
1030
1028
1026
1024
1022
1020
1018
1016
2/01/55
2/01/65
3/01/75
3/01/85
4/01/95
4/01/05

Figure 18. Estimated positions of upper and lower margins of *Chara* beds, Great Lake (green lines), lake levels (blue lines) over the period 1900 - 1955.

Red sloped lines indicate periods of exposure of upper sections of *Chara* beds during rapid drawdown (> 2m /year).

Blue horizontal lines at A are original summer (solid) and winter (dashed) lake levels (after Von Guerard, see text).

Vertical dashed blue lines indicate timing and FSL's for the 1910 and 1922 dams.



1038
1036
1034
1032
1030
1028
1026
1024
1022
1020
1018
1016
A
0/01/00
31/12/09
1/01/20
1/01/30
2/01/40
2/01/50

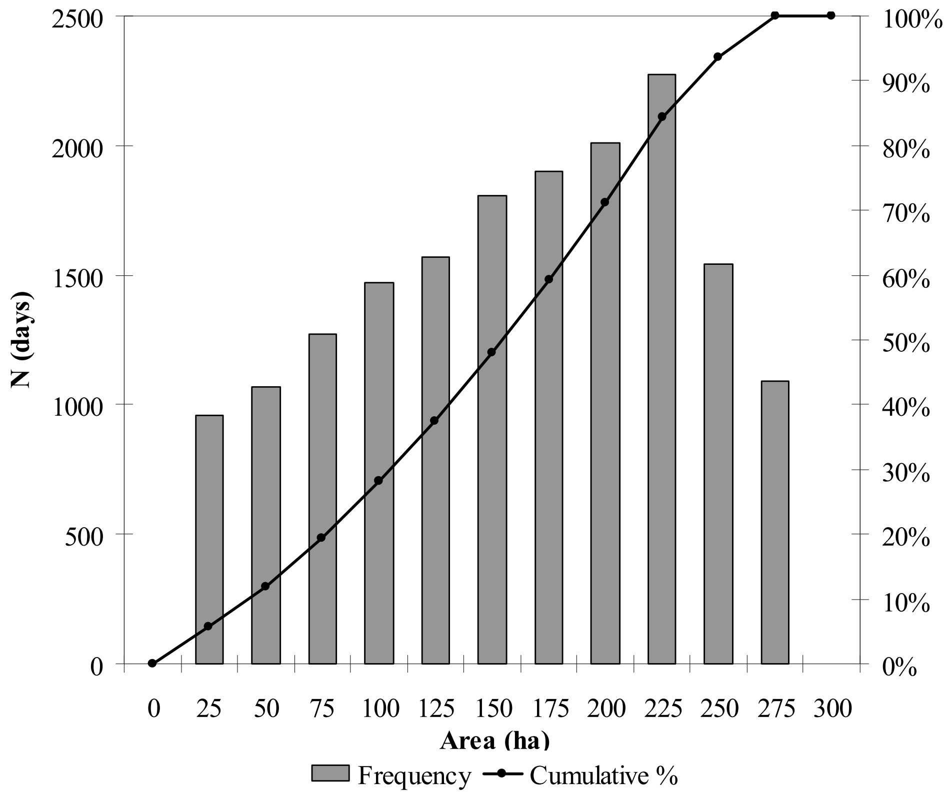


Figure 19. Frequency and cumulative frequency of occurrence of modelled total area of *Chara* habitat in Great Lake from 1955 to 2001.

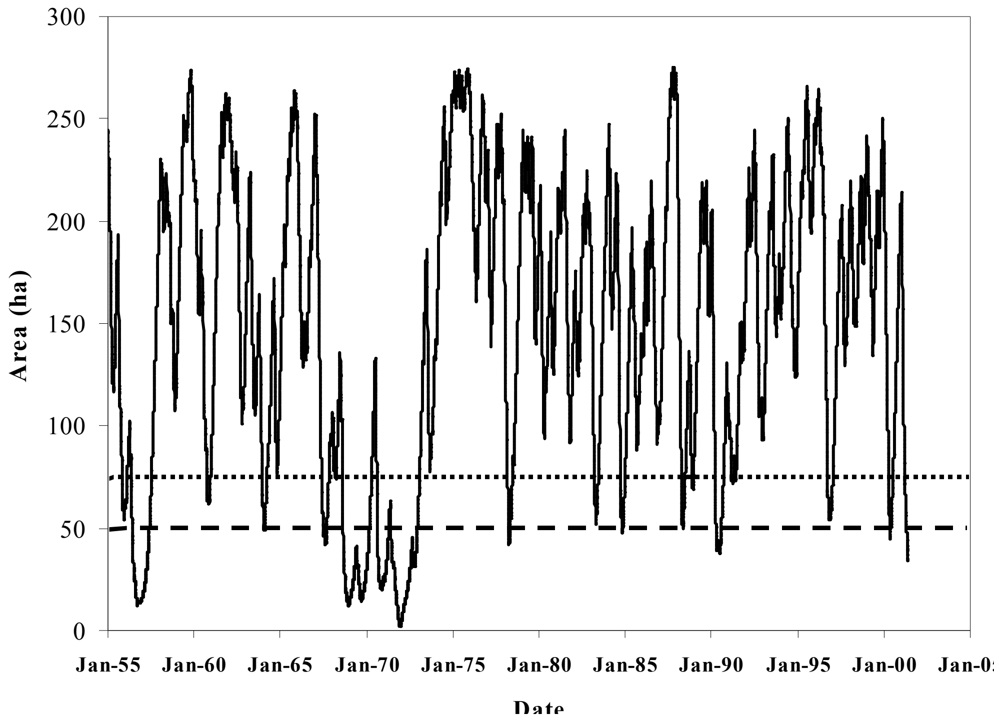


Figure 20. Time series of modelled total area of *Chara* habitat in Great Lake from 1955 to 2001. Horizontal fine dashed line shows lower 20 percentile value. Coarse dashed line shows proposed 50 ha limit.

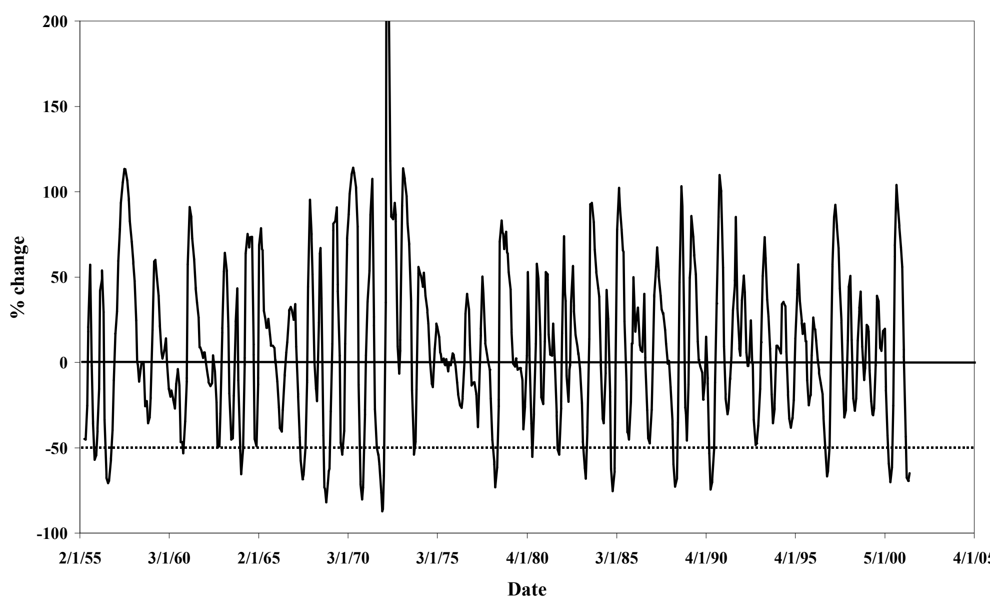


Figure 21. Time series of % 3-monthly change in modelled total area of *Chara* habitat in Great Lake from 1955 to 2001. Horizontal fine dashed line indicates 50% loss in habitat area over 3 months.

4.3. Management Implications and Recommendations

4.3.1 Variation in *Chara* habitat availability

It is apparent that the *Chara* bed habitat in Great Lake is mobile in response to changes in Great Lake levels. This occurs in the short term i.e. on an annual time scale, as observed by comparing surveys between late 1999 and early 2001. It also occurs in the long term, as observed by comparing the results of the two recent surveys with that in 1987. Great lake has historically shown long-term patterns of lake level rise and fall with a periodicity of around 10-20 years. Six of these trough-peak sequences have occurred since records commenced in 1917. Harris, Davies et al. (1988) found that these long-term sequences were in synchrony with a number of climatic features which were coupled with the El Nino Southern oscillation. They are therefore primarily climatically driven, given the relative constancy of the demand from the lake for Hydro generation over the last 45 years. It should be noted that, after correcting for rises associated with changes in storage full supply levels (four increments in dam height), there is no apparent climate-driven long term trend in Great Lake levels.

It is anticipated that the severe declines in level below ca 50 ha in area were associated with significant impacts on the fauna of the *Chara* beds, and hence the status and vigour of populations of endemic freshwater fauna. Figure 21 shows that the relative decline in *Chara* area over 3 month time steps is frequently large (indicated by substantial negative % changes), and has exceeded 50% in any one 3 month period 15 times since 1955, with seven such events happening since 1980.

4.3.2 Recommended shift in management focus

It is highly likely that the frequent declines in the remnant *Chara* habitat have both contributed to the threatened status of many of the lake's endemic invertebrates. This has obviously historically followed the original raising of the lake in the 1920's, which was associated with the loss of emergent and submerged rooted macrophytes (as recorded in the diaries of Colonel Legge, and the1874 painting by Von Guerard). However, we strongly recommend that current water management should focus on the reducing the rapid losses and variability in area of *Chara* habitat. It appears that the a majority of the aquatic conservation values of the lake depend on the viability of *Chara* habitat. In addition, Davies and Sloane (1988) and Davies and Fulton (1987) suggested that the brown trout fishery was also largely dependent on the *Chara* areas as foraging habitat.

There is no indication of a net loss in *Chara* habitat since records begin as a result of lake level fluctuations and hydro management. However, the key issue is the incidence of critical habitat-limiting events which have occurred both frequently and with occasional severity.

It should be noted that, while *Chara* may become re-established following severe depletions, the fauna may not. We assume that a significant proportion of this fauna would be significantly negatively impacted during periods when the area of *Chara* habitat is severely reduced, even if these reductions are only of the order of several moths in duration. *Chara* habitat loss is highly likely to lead to displacement, increased predation risk and reduction in food resources for these species, with consequent impacts on the viability of populations and the species status.

We recommend a shift in management focus for Great Lake to ensure maintenance of endemic fish and macroinvertebrate species, as well as the brown trout fishery, through:

- maintenance of *Chara* habitat above 75 ha at all times;
- elimination of events in which *Chara* habitat declines by 50% or greater in any one-year period.

4.3.3 Recommended operating rules

The following operating rules for the storage should allow these objectives to be achieved:

1. *Water level declines:*
    - Never to exceed 4 m in any one year;
    - Where possible to be < 2 m in any one year;
    - Where level declines of between 2 and 4m occur in a year, the level decline in the following year must not be allowed to exceed 2 m

2. *Water level rises:*

- When levels have fallen to 1022 m or less, subsequent rises must be controlled to be 2 m or less per year until the annual (typically October-November) peak in level is equal to or less than the previous year's annual peak.

5. Ongoing monitoring

We recommend two programs of ongoing monitoring, one focused on the position of *Chara* beds, the other on faunal status.

5.1 Chara beds – routine monitoring

Annual or biennial survey of the primary *Chara* beds in Great lake should be conducted against fixed datum points, in order to assess the position of the beds. Key aspects to be measured are the positions of the upper and lower margins of the beds, as well as the condition (cover and height) of he beds themselves. These data should be used to refine the current estimate of maximum upslope and downslope rates of movement of the beds and to refine the operating rules recommended above.

5.2 Chara beds – full mapping

A single survey should be conducted to assess the complete distribution of *Chara* beds within the lake. This current survey confirmed the existence of several new beds in the northern part of the lake that either didn't exist previously or were not previously detected. This macrophyte should be used to refine the estimate of area of *Chara* habitat within the lake, as the current estimates are based on the major beds alone.

5.3 Great lake fauna – condition monitoring

Periodic surveys of benthic fauna in Great Lake, focusing on both *Chara* and non-*Chara* habitats, should be conducted to ascertain the status of endemic and threatened species. This should be done on a 3-5 yearly basis, with an emphasis on assessing rhe success of the changed operating rules, if they are adopted.

6. References

Banks MR (ed.). 1973. The Lake Country of Tasmania. Royal Society of Tasmania, Symposium, Poatina, November 11-12, 1972. Hobart Tas.

Davies PE and RD Sloane 1987. *Chara*cteristics of the spawning migrations of brown trout, *Salmo trutta* L., and rainbow trout, *Salmo gairdneri* Rich., in Great Lake, Tasmania. Journal of Fish Biology 31, 353-373.

Davies PE and RD Sloane 1988. Long term changes in brown trout, and rainbow trout populations in Great Lake, Tasmania. North American Journal of Fisheries Management 8, 463 - 474.

Davies PE and W Fulton 1987. The Great Lake trout fishery. Inland Fisheries Commission Newsletter, Special Edition, 16 (2): 1-12.

Fulton W 1983. Macrobenthic fauna of Great Lake, Arthurs Lake and Lake Sorell, Tasmania Australian Journal of Marine and Freshwater Research 34, 775 – 785.

Harris GP, Davies PE, Nunez M and G Meyers 1988. Interannual variability in climate and fisheries in Tasmania. Nature 333.

Appendix 1. Chara bed transects, May 2001.

Black line = bottom profile (plotted as altitude).

Blue line = % cover of Chara.

Green line = Height of Chara (cm)