# A PRELIMINARY LIMNOLOGICAL SURVEY OF THE WOOLI LAKES, NEW SOUTH WALES

B. V. TIMMS*

*Sciences Department, Avondale College, Cooranbong, N.S.W.*

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*Synopsis*

Near Grafton there are two freshwater lakes, Hiawatha and Minnie Water, which were formed by coastal sand dunes blocking two depressions in the Fitzroy Beds. In both lakes the slightly acid water has less than 100 p.p.m. of total dissolved solids and is dominated by Na and Cl ions. The lakes are polymictic. The fauna and flora is poor in variety, but in some groups is rich in numbers. The zooplankton is dominated by *Calamoecia tasmanica*, but *Mesocyclops leuckarti* and *Bosmina meridionalis* are also present. A comparison of these lakes with typical sand dune lakes in northern N.S.W. and southern Queensland shows that the modes of origin are different, leading to different water chemistry, which probably accounts for the interesting differences in the zooplankton.

## INTRODUCTION

Near the coastal township of Wooli and about 40 km. east of Grafton by road in the North Coast District of N.S.W. lie two freshwater lakes, Lake Hiawatha and Lake Minnie Water (Fig. 1). They are situated close to the sea (the eastern shore of Hiawatha is only 2 km. from the coastline) and separated from it by sand dunes. The lakes are similar to those of the coastal acidic sand-dune series studied by Bayly (1964), but there are important differences.

## METHODS

The lakes were visited on two occasions in 1967—August 24–25 and December 30–31. Temperatures were measured with a resistance thermometer at 1 m. intervals until the bottom of the lake was reached. Readings were taken at five different places in each lake and were made in the mid-morning. The methods of water analyses and the plankton nets were the same as those used in Timms (1967). Parts of this report, particularly the sections on physiography and fish, are based on the unpublished data of other workers (see acknowledgements).

## PHYSIOGRAPHY

The two lakes lie in two depressions in a north-south line between Silurian Fitzroy Beds of shales, slates and phyllites in the west and recent siliceous sand-dunes to the east. McElroy's map (1962) of the area is inaccurate in that it shows the lakes completely surrounded by Quaternary deposits. The sand-dunes form a continuous ridge running roughly in a north-south direction reaching an altitude of 100 m. immediately north-east of Lake Minnie Water. The two depressions are separated by a bar of Fitzroy Beds which varies in height from about 20 m. in the east to about 30 m. in the west above sea-level. It is probable that the lakes lie on the same

* Present address, Monash University, Clayton, Victoria, 3168.

Beds in the west and in the centre, while in the eastern part they lie over the base of the sand-dunes (Fig. 2).

Lake Hiawatha is 315·6 hect. in area and 16·8 m. above sea-level, while Lake Minnie Water is 51·4 hect. in area and 19·8 m. above sea-level. No permanent streams flow into the lakes with most of the water entering by seepage and by surface runoff from the western ridge. During normal and

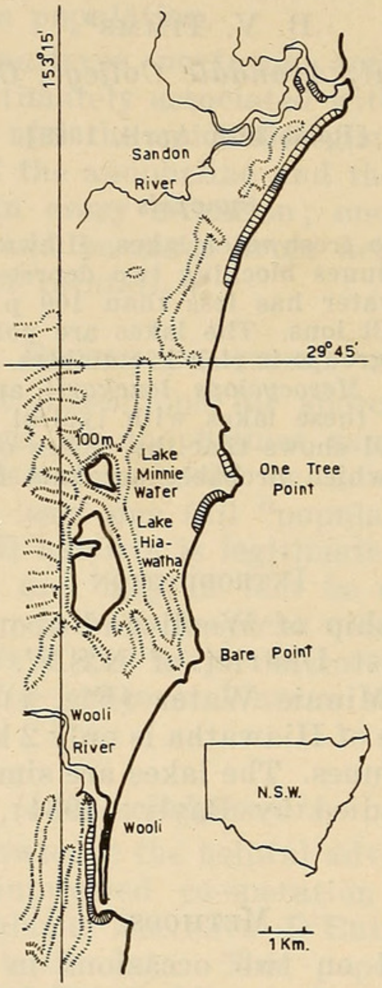


Fig. 1. Locality map of the Wooli Lakes showing the lakes with respect to various physiographical features. Outcrops of organically-bound sand are shown as hatched areas. In these the closer the lines then the more extensive the outcrop.

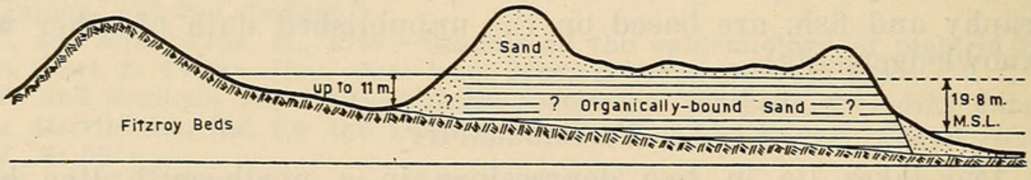


Fig. 2. Diagramatized and idealized profile through Lake Hiawatha from the western ridge to the coast. The relationship between the lake and sea level and between the rock base, organically-bound sand and sand dunes is shown.

subnormal rainfall periods Lake Minnie Water has no overflow, but during exceptionally wet periods it overflows into Lake Hiawatha. The latter lake has a semi-permanent overflow in the south-east corner. This outflow passes into swamps and then into the Wooli River. In both lakes the water level is known to vary no more than 1 m., even in times of severe drought. The maximum depth in Hiawatha is 11 m. and in Minnie Water, 9 m. The average yearly rainfall for the area is of the order of 1·25 m.

The physiography of the littoral areas in both lakes is variable. Basically three types can be distinguished: (i) a gently sloping littoral area of a clayey material studded in places with claystone outcrops—found wherever the lakes directly abut the Fitzroy Beds; (ii) sandy littoral area—associated with the sand-dunes on the eastern shore of both lakes; gently sloping in Hiawatha, but much steeper in gradient in Minnie Water; (iii) a peaty littoral area found wherever there are swampy areas near the lake edge—gradient is variable and in places the peat layer is undercut giving rise to an abrupt drop of 2–3 m. beyond the edge. The peaty littoral area is well developed and extensive in Minnie Water, but in Hiawatha it is limited to a small area at the northern end.

Some information is available on the nature of the benthic substrata in the lakes. Over the claystone it is generally of a colloidal ooze nature, though in places it is gravelly. The benthic material is sandy in the eastern section of the lakes. In the deepest part of Hiawatha there is an accumulation of leaves and reed debris to a depth of almost a metre.

Apparently there is no published information on the method of origin of the Wooli Lakes. The lakes were probably due to building up (possibly in Pleistocene and Recent geological time) of a dune barrier upon the truncated deposits of an old (Pleistocene) swamp now about 17 m. above sea-level. Evidence for the old swamp is seen in the outcropping of peat and organically-bound sand to the north, east and south of the lakes. This material probably acts as a water table in the eastern side of the lakes and is responsible for the retention of water between the dunes and Fitzroy Beds.

## Physical and Chemical Features

The temperature profiles for the two lakes are shown in Fig. 3. In winter the lakes were isothermal and no doubt in complete circulation. In summer there was only 1° difference between the bottom and surface temperatures

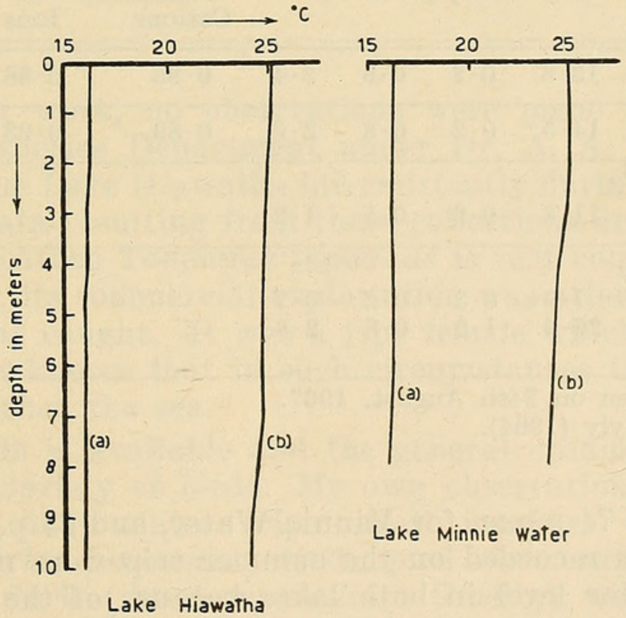


Fig. 3. Temperature profiles for the Wooli Lakes. Winter profiles are marked (a) and summer profiles are marked (b).

in both lakes, and so it is probable that during the night the lakes are in complete circulation. Thus, it would appear that the lakes are polymictic. The main contributing factor to this condition is thought to be the exposure of the lakes to wind, though the clear water would allow heating to some considerable depth.

Both lakes contain clear water with Secchi Disc readings of 473 cm. (August) and 337 cm. (December) for Lake Minnie Water, and 420 cm. (August) and 560 cm. (December) for Lake Hiawatha. From afar off the lakes appeared bluish, but Minnie Water tended towards a light humic brown colour on the summer trip.

Both lakes are acidic, and average pH values from a number of readings over the years are 6·2 for Minnie Water, and 6·5 for Hiawatha. The values for total dissolved solids for the August trip are given in Table 1. The

TABLE 1

*Percentage composition of cations and anions and T.D.S. in p.p.m. in coastal sand dune lakes*

| Locality | Na | K | Ca | Mg | Cl | $HCO_3$ | $SO_4$ | T.D.S. |
|---|---|---|---|---|---|---|---|---|
| Lake Minnie Water .. | 80 | 1 | 5 | 14 | 77 | 17 | 6 | 79 |
| Lake Hiawatha .. | 80 | 1 | 5 | 14 | 72 | 18 | 10 | 69 |
| Mean of 19 Qld–N.S.W. lakes* .. .. | 78 | 2 | 4 | 16 | 82 | 2 | 16 | 39 |

* From Bayly (1964).

TABLE 2

*Chemical composition of coastal acidic lake water*

| Locality | Na | K | Ca | Mg | Total ionic concentration (m-equiv./l) Summation of Cations | Summation of Ions | Cl | $HCO_3$ | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|
| | in p.p.m. | | | | | | in p.p.m. | | |
| Lake Minnie Water* .. | 13·8 | 0·2 | 0·8 | 2·4 | 0·85 | 0·88 | 27·0 | 6·1 | 1·9 |
| Lake Hiawatha* .. | 14·5 | 0·2 | 0·8 | 2·6 | 0·89 | 0·93 | 27·7 | 6·7 | 3·8 |
| Mean of 19 Qld–N.S.W. coastal acidic lakes† | 11·8 | 0·6 | 0·5 | 1·2 | | | 19·1 | 1·6 | 5·1 |
| Range of values in the 19 Qld–N.S.W. lakes† .. | 7·9<br>26·3 | 0·3<br>1·2 | 0·2<br>0·8 | 0·7<br>2·8 | | | 12·5<br>43·3 | Nil<br>3·0 | 2·4<br>12·5 |

* Water sample taken on 24th August, 1967.
† From Table 1, Bayly (1964).

December values are 74 p.p.m. for Minnie Water, and 67 p.p.m. for Hiawatha. The decreased values recorded on the summer trip were no doubt associated with the rise in water level in both lakes because of the abundant summer rains.

Tables 1 and 2 show the chemical composition of the water of the Wooli Lakes. As would be expected from their origins, the water chemistry of the two lakes is very similar. Sodium completely dominates the cations and chlorine the anions, the most common condition in Australian lakes (Williams, in Weatherley, 1967). As discussed later, there are important similarities and differences between the water chemistry of the Wooli Lakes and that of the coastal sand dune lakes studied by Bayly (1964).

### Biological Features

Around the shores of both lakes, emergent hydrophytes are abundant, though they are sparse in areas where there is outcropping rock. On all types of littoral shores (see earlier) there is a pure stand of the sedge *Lepironia articulata* (Retzius) on the outer edge and often continuing right to the shoreline. In places this species was found to be growing in water up to 3 m. deep. Other common emergent plants growing in the littoral region include a spike-rush *Eleocharis sphacelata* (Brown) and a pipe-wort *Eriocaulon scariosum* (Smith). Only two submergent species of hydrophytes were found. Thus there were numerous plants of *Restio pallens* (Brown) on some areas of the clayey shoreline of Hiawatha, and *Nitella* sp. (cf. *N. tasmanica* (Muhlenberg)) grew abundantly in parts of the littoral area in Minnie Water.

In Minnie Water the bottom was covered by a dense mat of hydrophytes. Two species, *Chara fibrosa* (Agardh) and *Utricularia flexuosa* (Vahl) were present, and from the limited number of dredgings taken it was apparent that each species occurred as pure stand and that *Utricularia flexuosa* grew on areas near peaty shorelines, and *Chara fibrosa* grew elsewhere in the lake. No macroscopic plants were found in the benthic zone of Hiawatha. No obvious reason could be seen for this difference.

Table 3

*Percentage composition of planktonic crustacean species in the Wooli lakes*

| Locality and date of collection | | *Calamoecia tasmanica* | *Mesocyclops leuckarti* | *Bosmina meridionalis* |
|---|---|---|---|---|
| Lake Minnie Water | 24. 8.1967 | 99·8 | 0·1 | 0·1 |
| | 31.12.1967 | 99·7 | 0·2 | 0·1 |
| Lake Hiawatha | 24. 8.1967 | 98·0 | — | 2·0 |
| | 31.12.1967 | 97·1 | 0·3 | 2·6 |

In the present work, no observations were made on fish, but a team from the State Fisheries Department under Dr. A. A. Racek collected fish (and decapods) from Lake Hiawatha intermittently during the period 1954–57. The unpublished data resulting from these collections are presented in Table 4. The freshwater catfish *Tandanus tandanus* is very common in the lake and in September, 1956, its commercial exploitation was attempted. At the time a 7 lb. sea mullet was caught. It was a ripe female which apparently did not spawn because it is known that in such circumstances the gonad is resorbed unless the fish reaches the sea.

No list of birds is available and the general opinion is that both lakes support a meagre variety of birds. My own observations are few. Thus, on both the summer and winter trips small numbers of black cormorant (*Phalacrocorax carbo* Linnaeus), little pied cormorant (*P. melanoleucos* Vieill) and black duck (*Anas superciliosa* Gmelin) were observed on both lakes. A few dusky moorhen (*Gallinula tenebrosa* Gould) were observed on both lakes in summer only while at the same time a number of a species of tern (*Sterna* sp.) were observed fishing in Lake Hiawatha.

In both lakes the limnetic zooplankton consists of three species of crustaceans, namely *Calamoecia tasmanica tasmanica* (Smith), *Mesocyclops leuckarti* (Claus), and *Bosmina meridionalis* (Sars). As shown in Table 3, *C. tasmanica* is the dominant species, and the only difference between the two lakes is the higher proportion of *B. meridionalis* in Hiawatha. The only phytoplankton species noted was *Botrycoccus* sp. No rotifers were observed, nor was the dipteran larva *Chaoborus*. An unidentified water mite was found in the August collection from Minnie Water.

Among the few insects observed were a number of corixid bugs and some larvae of Odonata and Trichopterā. Although snails and prawns were specifically looked for in the littoral area none were found. However, many specimens of an atyid prawn, *Caridina* sp. (of the *"nilotica"* group of species) was collected from the benthic region of Lake Minnie Water, it being associated with the masses of *Chara fibrosa* brought up with the anchor. Four littoral species of entomostracans were collected. These are *Eucyclops serratulus* (Fisher), *Paracyclops fimbriatus, Mesocyclops* sp., cf. *leuckarti* group and *Acroperus harpae* (Baird). None were common, being represented by only a few individuals in three five-minute collections at each lake.

TABLE 4

*List of fishes found in Lake Hiawatha**

| Fish | | Notes |
|---|---|---|
| Latin name and author | Common name | |
| *Tandanus tandanus* Mitchell | Freshwater catfish | Common in lake |
| *Anguilla australis* Schmidt | Short-finned eel | In outlet |
| *Mugil cephalus* Linn. | Sea mullet | Possibly introduced by local fishermen |
| *Pseudomugil signifer* Kner. | Blue eye | Only two specimens found in lake |
| *Melanotaenia fluviatilis* (Castelnau) | Rainbow fish | Abundant along eastern shore |
| *Galaxias attenuatus* (Jenyns) | Common jolly-tail | In outlet |
| *Carassiops galii* Ogilby | Fire-tailed gudgeon | Abundant along eastern shore |
| *Gambusia affinis* (Baird and Girard) | Mosquito fish | In most of the lake's areas |
| *Retropinna semoni* (Weber) | Australian smelt | In outlet |
| *Ambassis agassizi* Steindachner | Chanda perch | In lake and outlet |
| *Rhadinocentrus ornatus* Regan | Porthole fish | Only one specimen found in lake |

* Unpublished data, Dr. A. A. Racek.

Racek's team recorded four species of Decapoda from Lake Hiawatha and its outlet. They are *Atya striolata* McCulloch and McNeill and *Cherax* n. sp. (to be described by Riek in a forthcoming paper) from the outlet, and *Paratya australiensis* Kemp and *Caridina* sp. (of the *"nilotica"* group of species) from the weeded parts of the lake. Despite an organized search, no Spongillidae, Ectoprocta, Lamellibranchiata or Palaemonidae were found in the lake. Thus by combining Racek's and the author's observations, it can be seen that there are no Mollusca in the lakes.

## DISCUSSION

Hutchinson (1957) has discussed and catalogued the various methods of origin of lakes. The Wooli Lakes provide a modified example of Type 60—the formation of a lake in a valley dammed by wind-blown sands. Thus, in the present instance, two depressions have been dammed by sand dunes, organically-bound sand within the dunes acting as control for the water-table. Jennings (1957) has cited some similar examples on King Island (Tasmania) where water is held in depressions between siliceous sand-dunes and granite hills by a layer of organically-bound sand.

The coastal acidic sand dunes in south-east Queensland and north-east New South Wales, and some lakes on King Island are formed in a different way, and, as pointed out by Bayly (1964), one that receives little mention in the limnological literature. In these cases the lakes occur in depressions within sand dunes, the water being withheld by an impervious seal of organically-bound sand.

There is a high degree of similarity in these two modes of origin, and thus one would expect to find similar but slightly different water chemistry between lakes of different mode of origin with the same area. Brand (1967) found this to be the case on King Island, and as shown below, this is so with the Wooli Lakes and the coastal acidic sand dune lakes of south-east Queensland and north-east New South Wales.

If the water chemistry of the Wooli Lakes and of the coastal acidic sand dune series studied by Bayly (1964) are compared, the following points emerge. Thus, the pH is acidic in both series, but is higher in the Wooli Lakes (an average of 6·35 compared to an average of 4·8, and a range of 4·1 to 6·0 in the coastal acidic sand dunes series (calculated from Bayly, 1964). The higher pH is probably associated with the relatively higher amount of bicarbonate in the Wooli Lakes (see Table 2 and later).

The average values for T.D.S. of 76·5 p.p.m. and 68 p.p.m. for Minnie Water and Hiawatha respectively are well above the average for the coastal acidic sand dune series (39 p.p.m.) but within the range 26–84 p.p.m. (calculated from Bayly, 1964) recorded for that series.

Table 2 shows the chemical composition of the water of the Wooli Lakes compared with the mean values and range of values for 19 coastal sand dune lakes in south-east Queensland and north-east New South Wales (Bayly, 1964). It can be seen that there are differences in the ionic composition between the two groups. While the values for Na and Cl are well within the range exhibited by the coastal sand dune lakes, and the values for K, Ca, Mg and $SO_4$ are near the extremes found in the same lake series, the amount of $HCO_3$ in the Wooli Lakes is much higher. As shown in Table 1 the proportions of the major cations are much the same in the two series (note that there is a small difference in the relative proportion of Ca and Mg in the two) but the proportions of major anions are quite different. As stated before, much of the water entering the lakes is by seepage from the sand dunes and it can be reasonably expected that this water is of much the same nature as that entering the coastal sand dune lakes. The higher amount of $HCO_3$ in the Wooli Lakes can only be attributed to water that has run off the western ridge.

The only limnetic entomostracan species found in the coastal acidic sand dune series is *Calamoecia tasmanica tasmanica*. The same species is present in the Wooli Lakes, but in addition two further species are present, although in small proportions (see Table 3). It is believed that this difference in faunal characteristics is associated with the difference in water chemistry between the two series. It is now known (Brand, 1967) that *Calamoecia tasmanica* is able to survive in a much wider range of chemical conditions than previously thought, and in light of this, its presence and dominance in the Wooli Lakes is not surprising. Apparently, the Wooli Lakes provide a marginal habitat for *Mesocyclops leuckarti* and *Bosmina meridionalis*.

In many respects, a similar case of change in planktonic fauna with changing chemical conditions, has been presented by Brand (1967). Thus, in sand dune lakes on King Island *C. tasmanica tasmanica* is restricted to lakes of lower T.D.S. and Ca content, while *Boeckella symmetrica* Sars occurs mainly in lakes of higher T.D.S. and Ca content. A number of entomostracans penetrating into waters of low T.D.S. and Ca content were recorded; two of these were *Mesocyclops leuckarti* and *Bosmina meridionalis*.

Summing up, it can be seen that though there are many similarities between the Wooli Lakes and the more typical coastal acidic sand dune lakes, they are different in at least three important aspects—mode of origin, water chemistry, and zooplankton. The somewhat different, but nevertheless related, mode of origin accounts for the slight differences in water chemistry, which is probably the reason for the presence of the two additional species in the zooplankton of the Wooli Lakes.

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