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PHYSICAL, CHEMICAL AND BACTERIOLOGICAL FEATURES OF SOME COASTAL LAKES OF THE RANGITIKEI-WANGANUI CATCHMENT BOARD REGION.

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ABSTRACT

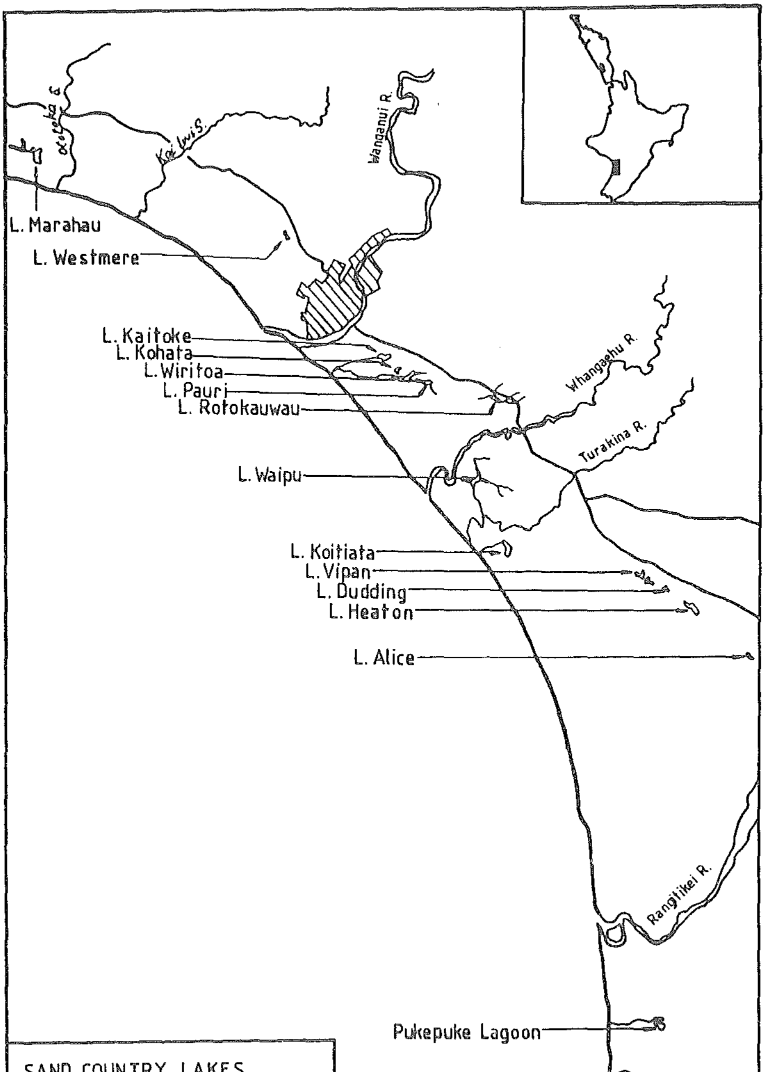
Physical, chemical and bacteriological features of 15 coastal lakes on the west coast of the North Island were investigated between 1977 and 1982. Considerable seasonal and comparative variations were found amongst the lakes, some of which stratified during the warmer summer months. At this time extensive algal blooms characterised most of the lakes. White's (1976) classification was used to evaluate the trophic conditions of the lakes. On this basis they were classified as mesotrophic, eutrophic or hyper-eutrophic.

KEYWORDS: lakes, Rangitikei-Wanganui, seasonal variation, water quality, trophic condition.

INTRODUCTION

Small dune lakes are important features of the coastal section of the Rangitikei-Wanganui Catchment Board region. Most occur within 10 km of the sea and were formed by the accumulation of rainfall in the dune complexes, as advancing dunes blocked natural drainage outlets to the coast. Lake level fluctuations may be extensive in response to variations in groundwater levels and localised run-off.

Physico-chemical and bacteriological features of 15 or these lakes (Figure 1) were investigated in the present study. Four of them were included in an earlier survey of coastal dune lakes made



SAND COUNTRY LAKES

FIG. 1 LOCALITY MAP

made by Cunningham et al. (1953). Two of the lakes (Whiritoa and Duddings) are used extensively by the public for recreational purposes, whereas some of the others are wildlife refuges (Pukepuke, Westmere and Kaitoke) or private shooting lakes. The majority have considerable value as wildlife habitats but limited fisheries value. The major use of the lakes situated on private property is as a source of stock water supply.

TABLE 1. MORPHOLOGICAL AND HYDROGRAPHIC DATA FOR THE SAND COUNTRY LAKES.

LAKE	ALTITUDE ABOVE SEA LEVEL	LAND CATCHMENT AREA	LAKE SURFACE AREA	LAKE VOLUME	LAKE SHORELINE	MAXIMUM LENGTH	MEAN WIDTH	MAXIMUM DEPTH	MEAN DEPTH	SHORELINE DEVELOPMENT
	(m)	(ha)	(ha)	($m^3 \times 10^3$)	(km)	(m)	(m)	(m)	(m)	-
MARAHAU-"MAC'S"	61	535	6.50	187.7	2.32	962	68	6.52	2.89	3.64
MARAHAU-"GREG'S"	61	596	14.09	1,071.3	2.25	740	190	15.50	7.60	2.39
WESTMERE	93	562	10.94	342.9	1.50	579	189	6.35	3.14	1.81
KAITOKE	21	3732	18.94	265.2	2.90	1220	155	2.22	1.40	2.65
KOHATA	60	61	8.24	399.8	2.89	1020	81	14.10	4.84	4.01
WIRITOA	45	1280	26.47	1,804.5	5.40	2025	131	20.40	6.82	4.19
PAURI	46	560	23.61	1,427.8	2.88	1137	208	14.95	6.04	2.36
ROTOKAUWAU	80	195	5.79	69.7	1.83	756	77	2.19	1.20	3.04
WAIPU	21	640	9.61	247.9	2.72	679	142	5.12	2.58	3.49
KOITIATA	20	632	16.05	380.5	2.56	772	208	4.22	2.37	2.55
VIPAN	75	136	24.49	404.5	4.70	1127	217	7.94	1.65	3.79
DUDDING	90	162	7.95	313.5	2.02	672	118	12.20	3.98	2.85
HEATON	91	1051	16.36	547.1	3.13	1127	145	4.90	3.34	3.08
ALICE	102	359	23.30	407.8	4.85	1482	157	3.97	1.75	5.67
PUKEPUKE	6	2819	16.30	118.6	2.06	630	259	1.30	0.73	2.03
KAIKOKOPU	7	4889	20.60	184.6	2.20	760	253	1.10	0.90	1.93

METHODS

Regular 3-monthly sampling programmes were underway in twelve lakes by late 1977, and similar programmes were begun in the other three (Lakes Koitiata, Rotokauwau and Marahau) in 1978. A minimum of two years was necessary to establish a seasonal pattern after which sampling frequency was reduced to twice a year (late winter and late summer), terminating in 1982. At least two sampling sites were chosen on each lake and surface and bottom water samples were collected if lake depth was 2 metres or greater. Sampling was performed near mid-morning by grab sampling directly from the surface waters and by "Van Dorn" bottle approximately 0.5 m above the lake bottom. The following survey and analytical methods were used:-

PHYSICAL

Depth contours were mapped for the smaller lakes from "plumb-bob" soundings taken from a small boat travelling along marked paths. In the large lakes echo-soundings were taken from a larger boat. Temperature measurements were made with a calibrated hand-held mercury thermometer, and the standard Secchi disc was used to measure transparency.

CHEMICAL

Alkalinity was measured titrimetrically using 0.02 N hydrochloric acid, to an end point pH of 4.2. Ammoniacal nitrogen was determined spectrophotometrically (at 630 nm) using the 'Hypochlorite-phenol' method on filtered samples which were chilled after collection. Dissolved oxygen was measured using the sodium azide modification of the Winkler method, with initial fixation done in the field. Calcium and total hardness were measured titrimetrically with E.D.T.; magnesium calculated as the difference between total hardness and calcium. Chloride was also measured titrimetrically with 0.282 N silver nitrate. Conductivity and pH were measured immediately on return to the laboratory by Radiometer CDM2f and Metrohm E512 meters respectively. Nitrate-nitrogen was measured spectrophotometrically using the "N.E.D.D." method (at 523 nm) after cadmium column reduction of samples chilled after field collection. Sulphate was determined turbidimetrically on the spectrophotometer at 340 nm and total reactive phosphate by the ascorbic acid method at 880 nm. Sodium and potassium were determined on two occasions (by the Palmerston North City Council laboratory) using flame photometry.

BACTERIOLOGICAL

Faecal coliform bacteria numbers were determined by the MFC technique, enumeration following 18 hours incubation at 44.5 C using MacConkey broth media (Taylor, 1958).

RESULTS

Physico-chemical and bacteriological data obtained from the 15 lakes are summarised in Table 2. Ranges shown were obtained from at least two surface and one bottom site in each lake, on 13 or more occasions. All data are lodged with the Rangitikei-Wanganui Catchment Board, Marton, and a more intensive (lake by lake) discussion of them can be found in Fowles (1982).

SECCHI DISC TRANSPARENCY

The widest ranges and highest transparency values were found in the deeper lakes (Fig. 2). Seasonal trends were apparent for most lakes with greatest transparency being measured in winter when water levels were highest. Increased algal growth, a feature common to all the sand country lakes in the warmer months, caused a rapid reduction in transparency. Two lakes (Waipu and Kaitoke) were exceptions to this general trend, as they carried fine sediment from localised run-off throughout most of the year.

TEMPERATURE

Wide ranges in temperature were recorded in all lakes as a result of their relative shallowness. Some degree of stratification occurred during summer, particularly in the deeper lakes (e.g. Wiritoa, Marahau (Greg's) and Duddings). This stratification was broken down rapidly by strong westerly winds common to the west coast of the lower North Island.

CONDUCTIVITY

The shallowest lakes (i.e. Pukepuke, Kaikopu and Kaitoke) exhibited the widest conductivity ranges and the highest recorded values (up to 1035 s at $25^{o}C$). Bottom water conductivities often were fractionally higher than surface waters due to the release of nutrients from lake sediment during stratification. Maximum conductivities in all lakes occurred in late-summer when lake water levels were low.

MAJOR CATIONS AND ANIONS

Concentrations of the major ions were high in comparison with most New Zealand lakes. This reflects the close proximity of the lakes to the sea, relatively large fluctuations in water levels in proportion to lake volume, and the influence of groundwater on water quality.

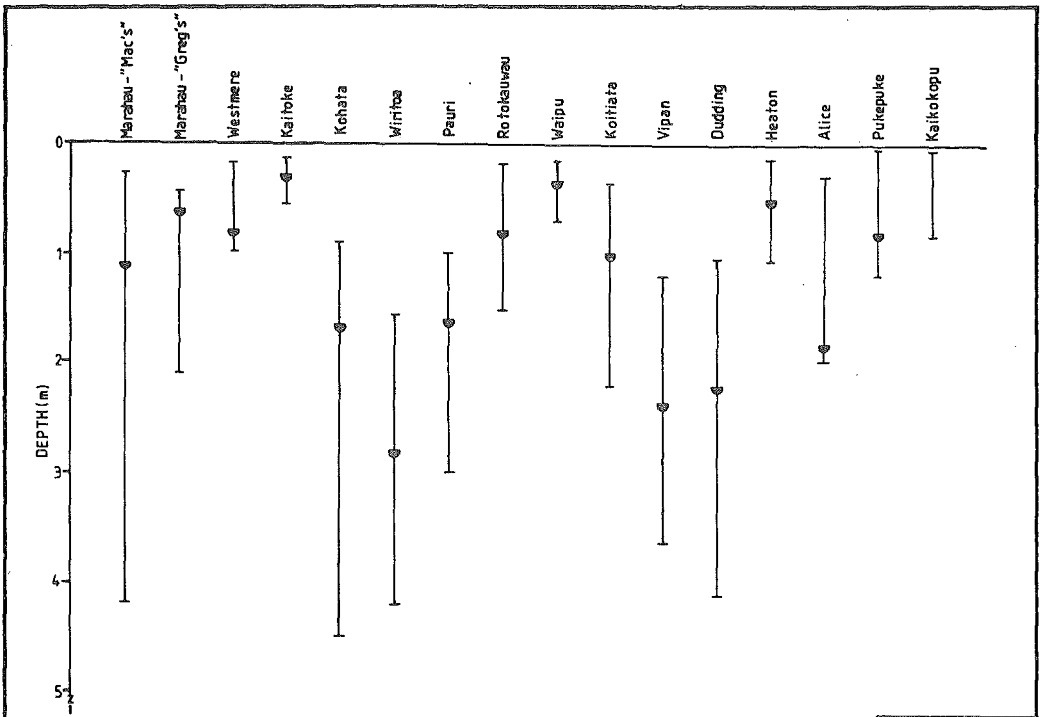
Most of the lake waters had major ion ratios of:

$$Ca > Mg; Na >> K : HCO_3 > Cl > SO_4$$

Ion-equivalent ratios for the spring survey of 1981 are tabulated in Table 3.

TABLE 2. RANGES OF PHYSICAL, CHEMICAL AND BACTERIOLOGICAL PARAMETERS FOR THE SAND COUNTRY LAKES. (S = SURFACE WATER; B = BOTTOM WATER)

LAKE		NO. OF SAMPLES	SECCHI DISC	TEMPERATURE	CONDUCTIVITY	SULPHATE	HARDNESS CALCIUM	HARDNESS MAGNESIUM	CHLORIDE	ALKALINITY	pH	DISSOLVED OXYGEN	NUTRIENT SPECIES NH_4-N	NUTRIENT SPECIES NO_3-N	NUTRIENT SPECIES TOTAL REACTIVE-P	FAECAL COLIFORMS	MAXIMUM DEPTH
			(m)	(°C)	μs/cm @ 25°C	mg/l	mg/l:$CaCO_3$		mg/l	mg/l: $CaCO_3$		mg/l	mg/l	mg/l	mg/l	nos/100ml	(m)
MARAEAU - 'MAC'S'	(S)	15	0.28-4.20	9.5-22.4	230-310	2.0-8.5	15-30	20-38	32-52	40-74	7.5-9.3	5.8-11.7	nil -0.40	nil -0.12	nil -0.02	2 - 552	-
	(B)	15	-	9.5-21.8	230-310	nil -9.0	17-30	19-42	36-50	42-82	6.4-8.4	nil -10.1	nil -0.98	nil -0.05	nil -0.13	-	5.50-6.50
MARAHAU - 'GREG'S'	(S)	15	0.42-2.15	9.7-22.4	255-305	2.0-7.5	16-26	22-38	40-54	49-62	7.4-9.1	3.6-12.3	nil -0.19	nil -0.10	nil -0.02	4 -6500	-
	(B)	15	-	9.6-16.9	265-340	nil-8.0	20-28	24-38	42-50	52-82	6.5-8.1	nil-10.3	0.32-4.67	0.01-0.09	nil -0.56	-	14.45-15.50
WESTMERE	(S)	23	0.20-1.00	8.3-25.3	250-345	1.5-12.0	28-55	32-58	32-48	72-112	7.7-10.0	4.0-18.7	nil-0.01	0.01-0.25	nil -0.09	2 -34,900	-
	(B)	23	-	8.3-21.8	255-340	1.5-11.0	30-56	24-54	32-44	74-108	7.0-9.0	nil-10.0	nil-1.30	0.01-0.27	nil -0.33	-	5.00-5.85
KAITOKE	(S)	18	0.13-0.57	9.1-23.0	210-495	2.5-17.0	22-60	33-66	22-64	54-138	7.4-9.8	3.1-12.8	nil-0.12	0.01-0.74	nil -0.64	4 -9,000	1.15-2.22
KOHATA	(S)	25	0.90-4.50	9.8-23.5	265-340	6.0-12.0	22-34	34-46	42-53	64-80	7.5-9.2	6.8-13.2	nil-0.03	0.01-0.23	nil -0.01	nil-140	-
	(B)	25	-	9.3-20.8	280-390	nil-12.0	22-34	33-51	42-52	62-112	6.6-7.9	nil-10.2	0.01-4.50	0.01-0.24	nil -1.14	-	12.70-14.10
WIRITOA	(S)	27	1.55-4.20	9.5-24.0	220-295	8.0-15.5	24-38	28-52	30-40	56-78	7.5-9.0	5.8-10.1	nil-0.02	nil-0.06	nil- 0.01	nil-226	-
	(B)	27	-	9.0-22.1	230-315	4.0-16.0	22-40	28-48	30-44	52-95	6.8-8.5	nil-10.3	0.01-0.75	0.01-0.06	nil- 0.34	-	18.40-20.40
PAURI	(S)	23	1.00-3.00	9.6-23.5	240-300	12.0-22.0	28-40	31-46	28-38	56-79	7.6-9.2	6.2-10.8	0.01-0.03	0.01-0.35	nil -0.02	nil-344	-
	(B)	23	-	9.0-20.4	240-340	12.0-18.0	28-42	30-56	30-38	56-108	6.3-8.3	nil-10.1	0.03-0.46	0.02-0.35	nil-0.31	-	14.00-14.95
ROTOKAUWAU	(S)	13	0.21-1.51	8.0-24.4	205-335	nil-25.0	30-58	26-52	20-46	62-112	7.1-8.9	3.8-13.5	0.01-1.26	nil -0.98	0.02-0.15	5 - 2,110	1.69-2.19
WAIPU	(S)	16	0.18-0.70	9.4-23.4	170-260	6.0-23.0	22-33	17-34	16-37	36-64	7.2-4.3	7.1-12.2	0.01-0.41	0.01-0.50	nil -0.19	nil-2,710	-
	(B)	16	-	9.3-20.7	165-255	4.0-22.0	22-34	20-34	16-37	37-64	7.2-8.5	4.7-11.0	0.01-0.45	0.02-0.43	nil -0.19	-	3.90-5.12
KOITIATA	(S)	13	0.40-2.20	8.5-25.3	455-600	5.0-36.0	70-144	49-72	58-82	90-184	7.7-9.2	1.4-15.4	nil-0.55	nil-0.33	nil -0.33	nil-3,400	-
	(B)	13	-	8.6-22.2	470-605	6.0-36.0	67-143	49-70	58-78	98-182	7.4-9.1	0.1-12.1	nil-0.45	0.01-0.01	nil -0.01	-	3.37-4.22
VIPAN	(S)	13	1.20-3.62	9.0-21.5	210-235	nil-5.5	20-34	23-40	24-30	60-74	7.3-9.2	4.7-10.9	nil-0.05	nil-0.01	nil- 0.01	nil-142	-
	(B)	13	-	8.9-21.2	210-255	nil-9.0	22-36	25-38	22-31	60-84	6.6-8.1	0.1-10.1	nil-0.53	nil-0.03	nil -0.18	-	6.90-7.95
DUDDING	(S)	21	1.02-4.10	7.7-21.9	140-190	5.0-10.5	10-26	20-42	16-24	36-62	7.4-9.4	7.5-11.1	nil-0.11	nil-0.33	nil -0.01	nil-456	-
	(B)	21	-	7.5-20.5	140-190	1.5-10.0	12-26	20-46	16-26	36-65	6.7-9.4	0.1-11.3	0.01-0.70	nil-0.27	nil -0.24	-	9.30-12.20
HEATON	(S)	18	0.22-1.05	7.6-22.2	185-315	2.5-20.0	22-41	27-52	16-34	54-92	7.5-9.9	5.2-12.7	nil-0.09	0.01-0.08	0.02-0.60	nil-3,850	-
	(B)	18	-	7.7-21.5	185-310	1.0-19.0	20-41	28-50	16-34	58-90	7.4-9.7	1.8-11.1	nil-0.12	0.01-0.08	0.02-0.61	-	3.80-4.90
ALICE	(S)	14	0.30-2.00	6.8-23.4	190-295	nil-11.0	22-45	18-40	19-32	52-97	7.5-10.1	7.3-13.5	nil-0.02	nil-0.07	nil-0.03	nil-750	-
	(B)	14	-	6.5-22.5	190-295	nil-10.0	23-44	22-40	19-32	54-96	7.3-9.2	0.6-13.3	nil-0.02	0.01-0.06	nil-0.03	-	3.12-3.97
PUKEPUKE	(S)	16	0.10- 1.20	7.9-22.2	555-935	7.5-31.0	64-142	68-162	64-139	148-302	7.5-10.5	4.2-16.6	nil-0.06	0.01-0.21	nil-0.39	nil-2,580	0.36-1.31
KAIKOKOPU	(S)	26	0.19- 0.85	5.6-23.4	555-1035	14.0-25.0	102-198	62-142	66-148	176-330	7.7-9.8	3.0-20.5	nil-0.18	0.01-0.17	nil-1.80	nil-1,000	0.60-1.10



SAND COUNTRY LAKES

FIG. 2 SECCHI DISC TRANSPARENCY [RANGES & MEDIANS (metres)]

Concentrations of the major ions varied seasonally in accordance with conductivity patterns. Little difference was found between major ion concentrations of surface and bottom waters except for sulphates which were much lower in the deeper anoxic waters during the stratified (late summer-autumn) period. At that time hydrogen sulphide (detectable by odour) was generally present.

pH AND ALKALINITY

Alkaline pH values common to all the lakes were the result of extensive photosynthetic activity. During summer stratification surface waters were more alkaline than bottom waters. Lake Westmere surface waters attained a pH of 10.0 during an algal bloom whereas bottom waters reached a pH of 9.0. In the deeper lakes it was usual for bottom water pH to become slightly acid during anoxic, stratified periods.

Large differences in seasonal pH values were measured in the productive shallow lakes. Lake Pukepuke pH varied between 7.5

TABLE 3. ION-EQUIVALENT RATIOS FOR SAND COUNTRY LAKES; SPRING, 1981 SURVEY.

LAKE	$HCO_3:Cl$	$HCO_3:SO_4$	$Cl:SO_4$	ANION RATIO	$\frac{Na + K}{Ca + Mg}$	Ca:Mg	Na:K	CATION RATIOS
WORLD AVE F.W.	7.25	4.58	0.63	$HCO_3 > SO_4 > Cl$	0.24	3.75	4.75	Ca>Mg : Na>K
MARAHOU-"Greg's"	0.88	22.80	25.80	$Cl > HCO_3 > SO_4$	1.35	0.86	9.00	Ca<Mg : Na K
MARAHOU-"Mac's"	0.82	7.38	9.00	$Cl > HCO_3 > SO_4$	1.39	1.02	7.27	Ca≥Mg : Na≫K
WESTMERE	1.36	4.35	4.78	$HCO_3 > Cl > SO_4$	0.74	1.40	16.43	Ca>Mg : Na≫K
KAITOKE	1.97	4.58	2.33	$HCO_3 > Cl > SO_4$	0.80	1.28	16.00	Ca>Mg : Na≫K
KOHATA	0.99	5.40	5.48	$HCO_3 = Cl > SO_4$	1.15	0.94	5.12	Ca≤Mg : Na≫K
WIRITOA	1.54	4.79	3.10	$HCO_3 > Cl > SO_4$	0.88	1.05	9.91	Ca≥Mg : Na≫K
PAURI	1.51	3.68	2.43	$HCO_3 > Cl > SO_4$	0.79	1.07	8.83	Ca≥Mg : Na≫K
ROTOKAUWAU	2.08	6.55	3.15	$HCO_3 > Cl > SO_4$	0.70	1.73	7.40	Ca>Mg : Na≫K
WAIPU	1.64	3.63	2.21	$HCO_3 > Cl > SO_4$	0.89	1.56	5.42	Ca>Mg : Na≫K
KOITIATA	1.94	7.02	3.63	$HCO_3 > Cl > SO_4$	0.44	2.70	12.92	Ca>Mg : Na≫K
VIPAN	1.63	31.80	19.50	$HCO_3 > Cl \gg SO_4$	0.84	1.35	8.60	Ca>Mg : Na≫K
DUDDING	1.53	4.65	3.05	$HCO_3 > Cl > SO_4$	0.90	1.09	8.22	Ca≥Mg : Na≫K
HEATON	1.90	3.23	1.70	$HCO_3 > Cl > SO_4$	0.73	1.35	13.00	Ca>Mg : Na≫K
ALICE	1.92	6.15	3.20	$HCO_3 > Cl > SO_4$	0.89	1.56	7.91	Ca>Mg : Na≫K
PUKEPUKE	1.66	5.84	3.53	$HCO_3 > Cl > SO_4$	0.62	1.35	9.26	Ca>Mg : Na≫K
KAIKOKOPU	2.24	14.16	6.53	$HCO_3 > Cl \gg SO_4$	0.49	2.21	9.95	Ca>Mg : Na≫K
SEAWATER	0.01	0.04	10.00	$Cl > SO_4 > HCO_3$	3.76	0.17	38.50	Ca<Mg : Na⋙K

during winter when lake levels, were high, and 10.5 in later summer-autumn when water levels were low.

All the lakes can be classified as "bicarbonate waters", as this ion dominated over sulphate and chloride ions (Table 3).

DISSOLVED OXYGEN:

Supersaturation was a common feature of the highly productive surface waters of all lakes during warm summer months. Lake Kaikokopu surface water reached a maximum saturation level of 225% due to algal photosynthetic activity. Decreases in surface dissolved oxygen, occasionally to levels less than 50% saturation, followed the die-off of macrophytes and algal populations, but levels generally recovered rapidly with the onset of colder temperatures and an increase in water levels.

Bottom waters of the deeper lakes lost dissolved oxygen rapidly with the onset of stratification and remained anoxic unless lake waters were mixed by strong westerly winds.

Less marked seasonal variations in dissolved oxygen were found in the shallower lakes which had high turbidities caused by fine suspended sediment, rather than extensive algal or weed populations, e.g. Lakes Waipu and Kaitoke.

NUTRIENT SPECIES

Variations and ranges were marked and complex for the nutrient species of the lakes studied in this survey (Table 2).

Highest concentrations of ammoniacal-N and total reactive-P were found in the de-oxygenated bottom waters of the deeper lakes during stratification. This was due to movement of phosphate and ammonium ions into the waters from the sediments, with concentrations reaching above 750 g NH_4-N/litre and 300 g PO_4-P/litre in most of the deeper lakes. Low nitrate-N concentrations were recorded in the bottom waters during these periods of stratification.

Surface water nutrient levels were generally low during summer until the die-off of algal and macrophyte populations and/or the mixing of lake waters, after which values rose toward their maximum levels. Nitrate-N tend to peak in late winter-early spring.

FAECAL COLIFORM BACTERIA

Most of the lakes exhibited wide ranges of faecal coliform numbers. High values were associated with the presence of large water fowl populations in late summer, but not farm run-off in winter. Median values for most lakes were less than 100 bacteria/100 ml and for the deeper lakes, less than 20 bacteria/100 ml. Lowest numbers were often found near mid-summer when algal populations were at a maximum. It was not uncommon to record nil counts during this period.

DISCUSSION

The 15 coastal lakes surveyed have various uses. These include abstraction of water for stock supply, wildlife habitats, and use for public recreation which is intensive in Lakes Dudding and Wiritoa in particular. Water quality variations affect all these uses, and problems are associated principally with extensive algal blooms. Low lake levels and high temperatures in summer months, coupled with nutrient release from underlying sediments, combine to produce conditions ideal for algal growth.

An assessment was made of the trophic condition of the lakes using White's (1976) "Multiple Use Classification for New Zealand Lakes". This involved the use of three parameters:-

i) secchi disc transparency,
ii) bottom water dissolved oxygen depletion,
iii) algal bloom occurrence.

A scale of penalty points (0 to 6) was awarded for each parameter and the higher the accumulation of penalty points the worse the trophic condition of the lake was considered to be. Transparency penalty points were substituted for bottom water dissolved oxygen depletion penalty points (i.e. they were doubled) in those shallow lakes which failed to stratify completely. Assignments of penalty points for algal growth were made on the basis of individual assessments over the survey period and were based on Kelly's (1978) plant survey. Detailed points assigned to each lake and discussion of problems encountered with the system are discussed fully by Fowles (1982).

The principal problems associated with the use of the penalty points system concerned the extremely shallow, readily mixed nature of the lakes, and the fact that secchi disc measurements could not distinguish between turbidity caused by suspended sediment or algal populations. Also, the definitions of terms relating to algal bloom development are imprecise. Nevertheless, the system offers a relatively simple method of lake classification for resource management requirements.

The following is a summary of penalty points allocated to each lake together with the status given to each lake on the basis of the total of penalty points.

LAKE	TROPHIC CONDITION PENALTY POINTS	STATUS
Heaton	17	Hyper-eutrophic
Kaikokopu	15	Eutrophic
Pukepuke	15	
Kaitoke	13	
Rotokauwau	13	
Westmere	13	
Waipu	13	
Alice	12	
Koitiata	12	
Kohata	12	
Pauri	12	
Marahau ("Greg's")	11	Mesotrophic
Marahau ("Mac's")	10	
Wiritoa	10	
Vipan	9	
Dudding	8	

A tentative inventory of 72 New Zealand lakes was produced by White (1976) using the penalty points system. Many of the lakes considered in the current study were given similar numbers of points to the more eutrophic lakes such as Rotorua (12 points), Ngapouri (13 points), Horowhenua (14 points), Hayes (15 points) and Tutira (17 points). The earlier survey of the coastal dune lakes by Cunningham et al. (1953) was limited in time and scope, but the few lakes which can be compared using the penalty points system indicate that conditions have deteriorated, particularly in Lakes Westmere and Heaton.

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